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Systems Analysis Department

Annual Progress Report 1993

Edited by Hans Larsen and Kurt E. Petersen

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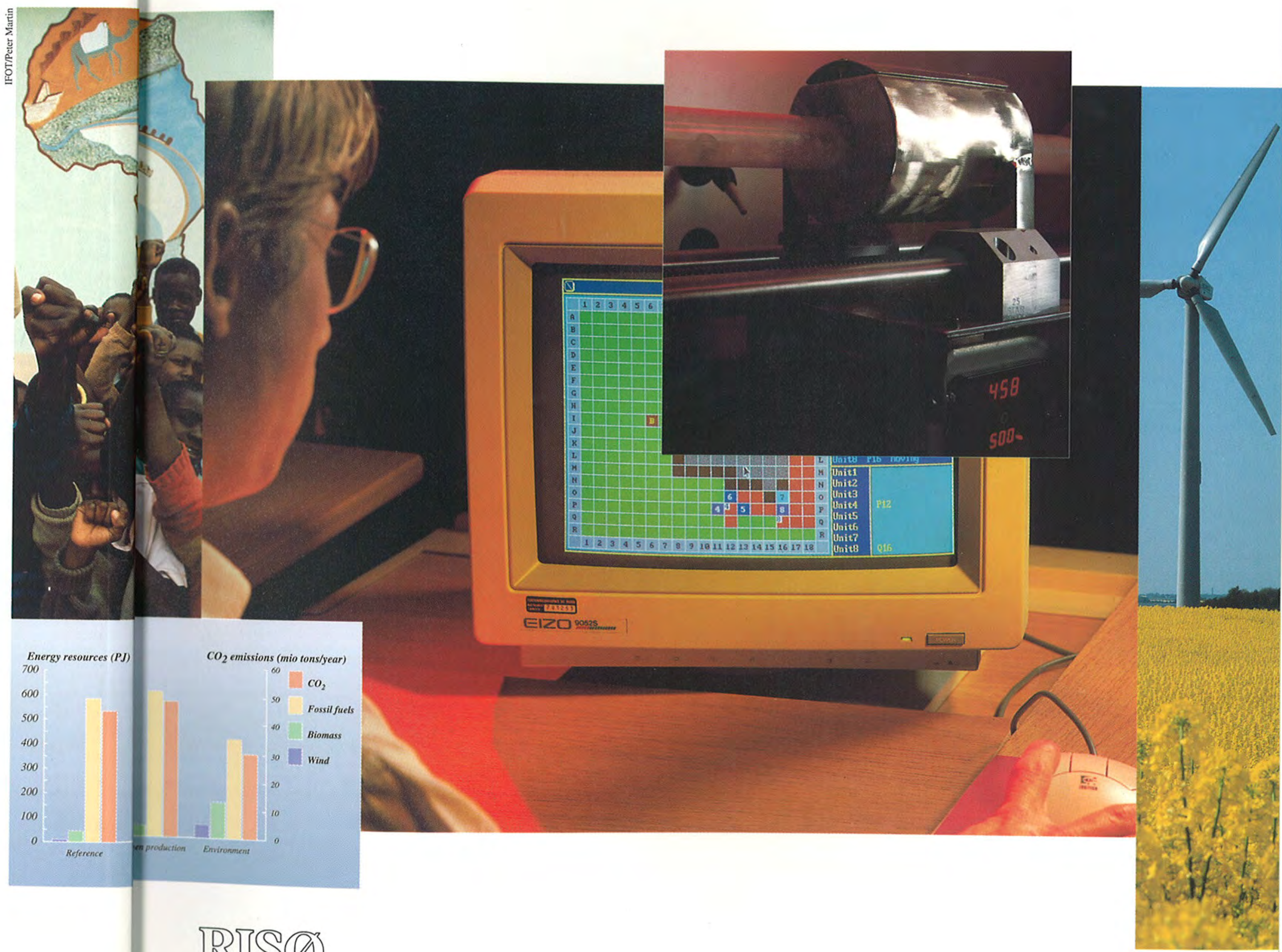

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Abstract

The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1993. The department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group, and the UNEP Collaborating Centre on Energy and Environment. The report includes lists of publications, lectures and staff members.

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New International Initiatives

By
Hans Larsen
Head of Department

1993 has been a year with an increasing level of activity in the department. A number of major international research projects were completed, and important new ones have been initiated. In particular a number of new projects have been launched directed towards developing countries and global energy and environmental issues.

The department consists of four groups:

- *Energy Systems Group (ESG),*
- *UNEP Collaborating Centre on energy and environment (UCC),*
- *Risk Analysis Group (RAG),*
- *COgnitive systems Group (COG)*

The activities of the department are multidisciplinary, and research and development focus on methods and models dealing with the interplay among various technologies, systems and humans. The total staff numbers 46 engineers, natural scientists and economists as well as social and behavioural scientists, of which 22 are senior scientists or economists and seven supporting staff. Six staff members are enrolled as Ph.D. students at various Danish universities, and two are post doc students. By the end of the year two new Ph.D. students have been engaged and will start their projects in the beginning of 1994.

The activities of the department in 1993 were financed 33% by government appropriations and 67% by funds derived from national and international research contracts and other types of contract work.

The activities of the department involve close collaboration with Danish and foreign universities, research institutes and industrial companies, as well as national ministries and international organizations such as the Commission of the European Communities, Nordic Council of Ministers, International Energy Agency (IEA), World Bank (WB), Intergovernmental Panel on Climate Change (IPCC), World Energy Council (WEC), United Nations (UN) and United Nations Environment Programme (UNEP).

A significant part of the research in 1993 was carried out under research projects supported by international research programmes such as EU: ESPRIT, Environment and Joule.

In 1993 the department has accepted to chair a new work group entitled *Local and regional energy-related environment issues* under the 1993-95 study programme of the World Energy Council.

Energy Systems Group

The Energy Systems Group undertakes research on *Simulation and optimization of energy systems.* In 1993 a new project has been launched with the aim of estimating the externalities related to energy production, with a focus on environmental externalities i.e. calculation of damage costs and abatement costs. Research has continued concerning the interplay between "bottom-up" and "top-down" modelling approaches. In 1993 two projects have been carried out in collaboration with the Danish utilities ELSAM and ELKRAFT, one analyzing the possibilities up to year 2030 for large-scale implementation of fluctuating renewable energy into the Danish energy system and another evaluating scenarios with hydrogen as energy carrier. The Energy Systems Group has been strongly involved in the UNEP Greenhouse Gas Abatement Study coordinated by UCC, and has been responsible for national case studies for Denmark and Zimbabwe. In 1993 work has continued on emission inventories. Furthermore, the group has contributed to a number of energy studies in Eastern Europe and developing countries, e.g. in Poland, Bulgaria and Egypt. Finally the group has participated in the work of the Intergovernmental Panel on Climate Change (IPCC), as one of the Danish representatives

UNEP Collaborating Centre

The UNEP Collaborating Centre on energy and environment has the overall aim of *promoting the incorporation of environmental considerations into energy planning worldwide, particularly in developing countries.* The Centre is financed jointly by the United Nations Environment Programme (UNEP), the Danish International Development Agency (Danida) and Risø. In 1993 the Centre had increased its staffing to 7 internationally recruited senior scientists and economists. The Centre has as part of its mandate to provide support to UNEP headquarters, in 1993 this has involved support to the Energy office , but also to other units, e.g. Climate and GEF. In 1993 the Centre has entered into new energy/environment activities in India, China, Sri Lanka, Zimbabwe, Venezuela and Argentina. In 1993 collaboration with Stockholm Environment Institute's Boston Centre (SEI) has focused on incorporating specific emission data from the European CORINAIR emission inventory into the LEAP/EDB database. In 1993 phase II of the UNEP Greenhouse Gas Abatement Study has been finalized with reports on methodological guidelines for calculating the costs of limiting greenhouse gas emissions especially from the energy sector. This study has included ten national studies, and a summary of the results has been presented separately by UCC.

Risk Analysis Group

The Risk Analysis Group conducts research on *Integrated environmental and risk management.* The activities involve development of tools and methods as well as their practical application. In 1993 work has continued on the TELEMAN and INGRID projects under the CEC's TELEMAN research programme with the aim of developing advanced teleoperators (robots) that can operate in hazardous or disordered nuclear environments. During the year several papers were published with results from the CEC STEP project *Combustion of Chemical Substances and the Impact on the Environment of Fire Products*, and a follow-up project *TOXFIRE - Guidelines for Management of Fires in Chemical Warehouses* was initiated by the end of the year. An important achievement in 1993 was the successful completion of the CEC JIVE project. Risø's contribution to the project was to perform experiments with horizontal natural gas jet flames. Finally, work has started on model evaluation; the group is chairing the CEC Model Evaluation Group.

Cognitive Systems Group

The Cognitive Systems Group is engaged in interdisciplinary research on *Man/machine interaction.* In 1993 two major Emergency Management projects have been initiated: MUSTER *Multi-user System for Training and Evaluation of Environmental Emergency Response* under the CEC ENVIRONMENT programme and MEMbrain *Decision-support Integration-platform for Major Emergency Management* within the framework of EUREKA with substantial financial support from the Danish EUREKA authorities. A major achievement has been the successful evaluation of the ESPRIT basic research project COMIC, *Computer-based Mechanisms of Interaction on Cooperative Work.* Furthermore, work has continued on the CEC-supported Telematics/AIM project KAVAS with the aim to develop a prototype tool to support medical professionals in their development of new medical procedures for treating patients. Finally, collaboration with the Danish Maritime Institute has been further intensified with regard to navigator training on a maritime full-mission simulator.


Nordfoto/ V.C.L.

Energy Systems Group

THE COST OF CO_2 REDUCTION IN DENMARK

The UNEP Greenhouse Gas Abatement Study was started in the autumn of 1991 with the main purpose of developing a common methodology for undertaking a cost assessment of greenhouse gas abatement, and to carry out a number of country studies by using this methodology.

The Danish project is part of this UCC study and has contributed in two ways:

- Denmark has participated in the development of the common methodological framework.

- The methodological framework is tested on Danish conditions, applying Danish planning tools, data and energy system forecasts, but using the common assumptions given by the UNEP project.

The Danish study was financed by the Danish Ministry of Energy.

Main reduction scenarios

Following the development of a baseline scenario, *two main reduction scenarios* have been constructed in the Danish case: *a)* a 20% reduction scenario for year 2005 and *b)* a 50% reduction scenario for 2030, taking as its starting point the 20% scenario for 2005.

The results show that it should be possible to reduce CO_2 emissions significantly at reasonable costs, both in the medium term (2005) and long term (2030). Reduction costs for 2005 are estimated as −100 DKK/t CO_2 reduced (negative cost), and +40 DKK/t CO_2 reduced for 2030.

Approximately 1/4 of the reduced quantities of CO_2 are realised through demand-side options. An important issue in the study is to use only realistic, realisable demand-side options. Reductions in demand are assumed to take place mainly through the introduction of standards for appliances, and a gradually increasing environment tax.

Approximately 3/4 of the reduced quantities of CO_2 are realised through supply-side options. The most important of these are increased numbers of connections to networks, comprehensive use of combined heat and power (CHP) and a development of the supply system towards an extensive use of biomass (biogasification plants), natural gas (combined cycle) and renewable technologies, especially wind power.

Cost curves

Based on the two reduction scenarios it is possible to construct the *medium-term cost curve* for 2005 and *long-term cost curve* for 2030. The marginal and average cost curves are given in Figure 1 for 2005.

The economically most attractive and the most efficient options with regard to CO_2 reduction can be grouped into three:

- *The utilisation of the existing excess capacity* in the Danish natural gas and district heating networks, including the use of CHP. For both networks the major part of the investments (transmission and distribution networks) are already undertaken, implying that only the marginal costs of connection and in-house constructions are to be incurred. In 2005 almost 4% CO_2 reduction can be achieved by these options to an economically very attractive cost (negative costs). Utilising the network capacity has a very favourable impact on the average cost of CO_2 reduction in Denmark. Leaving these options out would decrease the CO_2 reduction to approximately 17% compared to the baseline and increase the average cost to approximately 15 DKK/t CO_2 reduced in 2005.

- *No-regret options on the demand side,* that is options that are economically attractive and CO_2 reducing at the same time. The most important of these options are electricity conservation in households and services and energy conservation in industry, reducing CO_2 emissions by approximately 6% in 2005 compared to the baseline.
- For the supply side the *utilisation of biomass resources* dominates the results in both scenarios. In 2005 biogasification reduces CO_2 emission by approximately 5% and the use of decentralised CHP-bio combustion reduces CO_2 emission by approximately 3%. Biogasification plants are assumed to be developed to a technological commercial level and be economically close to break-even in 2005.

Resource bottlenecks

A major assumption in these analyses is that the energy resources are actually available. The long-term scenario depends particularly on the use of biomass and natural gas. The total use of biomass is calculated to be 162 PJ in 2030 - the total potential of biomass is estimated at 100 PJ in the Energy 2000 plan excluding the possibilities for energy harvest. The potential might be increased by the laying fallow of 15-20% of farmland, but how much it will increase is very uncertain. Finally, although the potential does exist, there might be problems with the localisation of the biomass.

The use of natural gas is increased significantly until 2030, amounting to 200 PJ that year. Due to the possibilities for importing gas this may not be a major limitation on the results, although a rapidly increasing demand for natural gas might lead to unfavourable price changes on this fuel.

Theoretical considerations

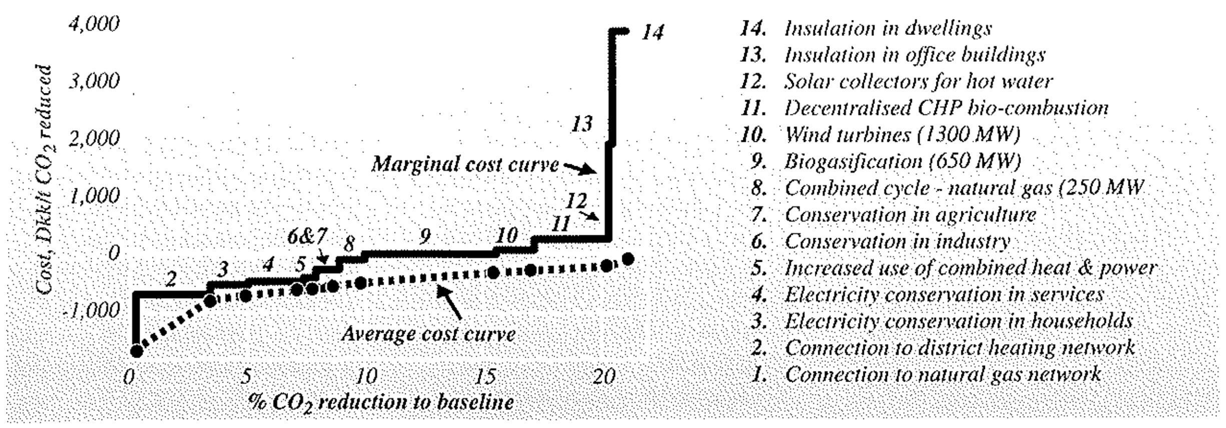
Theoretical problems exist in calculating the cost curves due to the interdependences among the options. It should be stressed that the results can be taken only as a rough indication of the magnitude of the cost and CO_2 quantities reduced, because the sequential ranking does not take into account that the estimated cost of the options that are taken might change when new options are introduced. The correct theoretical approach is to observe the scenario as an integrated analysis.

It should be stressed that each analysis is performed using socio-economic prices, that is prices stripped of taxes and subsidies. Moreover, only direct costs are included in the calculations. Costs incurred in implementing the conservation measures, search costs to identify the options, adjustment costs in industry and services, and welfare losses due to public intervention are not included.

Finally, the uncertainties related to these long-term calculations are of course considerable. Given these reservations, however, there seems to be sufficient economic background to conclude that even a substantial reduction of CO_2 will not place a heavy burden on the Danish national economy.

Publications in 1993: 16

POUL ERIK MORTHORST



Medium-term cost curve for CO_2 reduction.

Danish Utilities in a Competitive Market

Traditional energy planning in most countries has been based on the idea of national autarky. Although a lack of indigenous resources of fossil fuels makes fuel import necessary in many countries, the electricity demand is generated nationally, most often by nationalized or public owned utilities. Denmark is no exception. However, electricity import has been considerable in some recent years, whenever hydro power has been abundant in Norway and Sweden.

The European internal energy market

At present, the legal framework for the European internal market for energy is the Transit Directive for electricity and natural gas from 1991, setting up rules for a free trade among utilities with a transit obligation for owners of transmission lines. This is only a step towards a system with "third party access" which is proposed by the Commission, but already exists in England and Wales, Norway and Sweden.

The likely consequences of competition on a European scale for the Danish electricity supply industry are studied in a project for the Danish Energy Research Programme with participation from the Institute of Local Government Studies, Roskilde University Centre and Risø. The main task of Risø is to adapt our modelling experience to a quantitative analysis of the new organizational framework.

Models for the Danish electricity and CHP system

ESG has long experience in scenario or optimization models for national energy systems, mainly for national energy planning purposes and for international comparative studies by international organizations. Typical study objectives have been the penetration of new technologies, impact of fuel price changes and optimal emissions reduction strategies.

The energy system is described as a network combining the extraction of primary fuels through a number of conversion and transport technologies to the demand for energy services or large energy consuming materials. The EFOM model is one of the tools for this modelling approach, which has been used by the ESG.

The power generating system is the central part of the energy system that is described here, including combined heat and power (CHP) mainly for district heating.

Sensitivity to economic parameters

Figure 1 shows some results of an application of this modelling approach for analyzing the Danish electricity system until 2010, emphasizing the impact of changing market conditions on the choice of new generating capacity and fuels. The model is developed from a study of CO_2 reduction strategies for the CEC.

The assumptions concerning demand projections and technology options are those that were specified for the energy plan "Energy 2000". The parameter variations concern:

- limits for electricity import and export
- import and export prices
- discount rate

In the Reference Scenario the Danish electricity system is optimized for the period 1995-2010 assuming only contracted import and export. Import and export prices are set constant over the year, the import price at 0.15 DKK/kWh for the whole period, assuming that most import is from hydro and nuclear sources in Norway and Sweden at low variable costs and limited access to a large market. The export price reflects long-term marginal costs for new coal-fired condensing power plants (0.28-0.32 DKK/kWh). The objective function for the linear programming problem is the total discounted costs for the period at 5% discount rate. A set of constraints reflect the infrastructure of the Danish electricity and CHP system, e.g. the maximum district heating market to be supplied from extraction-condensing plants. There are constraints for SO_2 and NO_X emissions from national sources, but not for CO_2 emissions. International electricity trade is constrained at a minimum.

In the next scenario "Import" maximum import is set at the capacity of the transmission lines to Norway and Sweden from 1994. The third scenario "More trade" sets maximum export in 1995 at the planned transmission capacity, and further expansion of the transmission capacity is assumed. In the "Mid-price" scenario the same price is set for both import and export, equal to the average of the import and export prices assumed for the first three scenarios. The last scenario assumes a discount rate of 10% in order to reflect the financial conditions for utility investment at a competitive market for electricity.

The optima for all the scenarios with unconstrained trade volumes are very sensitive to changes of the import and export price assumptions.

Most electricity is generated at central thermal stations, either as combined heat and power or electricity-only generation. The volume of the latter will mirror the variations in import and export volumes. Investment in wind power by the end of the period is quite insensitive to variations in the assumptions, while the optimal investment in decentralized CHP is very sensitive to the export volume and the discount rate. A general conclusion for capacity planning is that the return on investments in new power stations will depend very much on the future daily operation, in particular the ability to meet the market opportunities.

Modelling electricity flows and supply costs in the transmission system

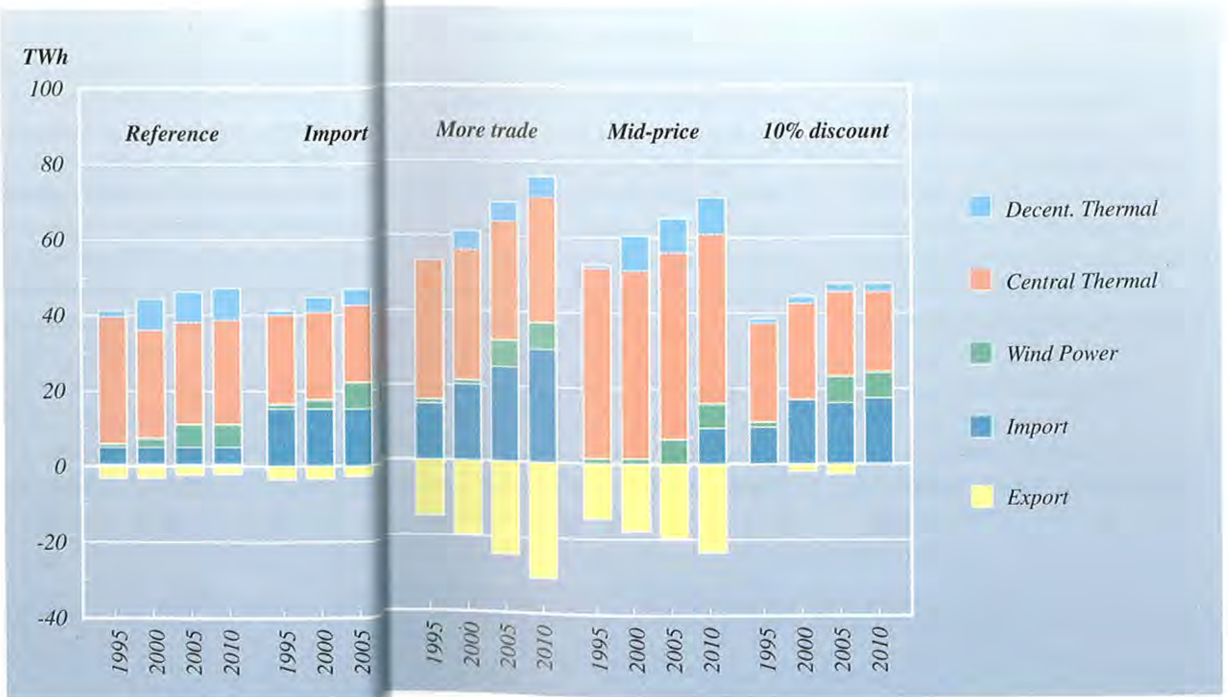
The long-term optimization model does not give an appropriate representation of electricity flows over time and space. The transmission of electricity from one place to another is subject to time variations, network capacity limitations and losses. Thus the assumptions are studied further by introducing a supplementary model for the analysis of the electricity flow and costs of supply in the transmission network, given the hourly regional demands and generating capacities. This model provides time and space differentiated marginal costs and prices, line and transformer losses are explicitely taken into account, and power flows over the transmission lines are determined by physical laws.

Electricity market with several agents

In the scenario models there were usually only one economic agent: the Danish electricity supply industry. This agent enjoys a monopoly at the distribution side. However, when foreign trade is possible, there is competition at the production side, even without further liberalization. This leads to an industry with more agents with similar or different system boundaries within which they will optimize, either by maximizing profits, minimizing costs or expanding their market share.

The tools for describing the strategic behaviour of the agents in such an oligopolistic market belong to other traditions, e.g., systems dynamics or game theory, or the tradition of financial analysis of spot and futures markets or utility regulation. The traditional engineering modelling approach is suitable for describing the features that are derived from the use of identifiable technologies, i.e. generating equipment, transmission and distribution grids, fuels and pollutants. These features are seldom satisfactorily represented in economic or financial models.

The quantitative analysis of the consequences of the changing institutional framework of the electricity supply industry requires a combination of these two approaches.



Electricity generation technologies in Denmark 1995-2010.

Poul Erik Grohnheit

Implementation of New Technologies in The Energy System

A part of the research work in the Energy Systems Group involves assessment of different new energy technologies regarding energy efficiency, environment and economic factors. In some projects the introduction of new attractive energy technologies in the energy sytem is assessed, and the consequences by implementing these technologies are estimated.

Hydrogen as an energy carrier

In the project "Hydrogen as an energy carrier" the utilization of hydrogen as an energy carrier in the future energy system in Denmark has been considered. The project has been financed by the utilities ELSAM and ELKRAFT and the Danish Energy Research Programme. The purpose of the project has been assessment of hydrogen as an energy carrier, and to point out economic and environmental consequences by implementing hydrogen in the future energy system in Denmark. The project was finalised with a report in 1993.

The whole hydrogen cycle from production to transportation to storage and utilization of hydrogen has been considered in the project. The most relevant technologies for the Danish energy system have been identified and used in different hydrogen scenarios. The scenarios have been evaluated using a simulation system consisting of two parts: The first simulates the operation of the energy system when introducing different hydrogen technologies, while the second assesses the consequences from a technical, economic and environmental point of view of introducing the different hydrogen technologies in the Danish energy system.

All calculations in the different hydrogen scenarios refer to the year 2030. It is therefore possible to assume major changes in the energy technologies on the demand side as well as on the supply side of the energy system. As a reference for the hydrogen scenarios, a modification of the basic scenario from the Danish energy plan "Energy 2000" has been used including supplement forecasts from the Danish Transportation Plan. The basic scenario is primarily based on central coal-fired CHP plants together with decentralised CHP and a small amount of wind energy.

3 types of scenarios have been analysed:

- Scenario concerning the electricity system.
- Scenario concerning production of hydrogen.
- Scenario concerning environmental impacts.

In the *scenario concerning the electricity system* hydrogen is introduced as part of a facility for electricity storage. When surplus electricity is produced by, for instance, wind energy the electrical energy in surplus is converted to hydrogen by electrolysis. Gasification of coal or biomass may also profitably be used for energy production in an energy system based on large amounts of renewable energy. The gasification combined-cycle plants may be used for electricity production in periods with low renewable energy inputs, e.g. low wind periods, while the gasification part of the plants in periods with large amounts of wind produced electricity may be used for high purity hydrogen production via a shift process. The gasification combined-cycle plants will function as a buffer for renewable energy. The hydrogen is stored in large caverns, and is utilized later on in the energy system in fuel cells.

In the *scenario concerning hydrogen production* it is expected that there is a need for hydrogen in the transportation sector, and the electric utilities are assumed to function as producers of hydrogen at low cost. Coal gasification plants extended with shift reactors may be used in the energy system for hydrogen production, as the gasification plants are able to produce hydrogen at a low price on condition that the gasification plants already exist in the energy system, and investments are needed for only the shift part of the process. Conventional plants in continuous operation are furthermore introduced, having few pieces of regulation equipment and thus the investments related are cheaper. Excess electricity from such plants is converted to hydrogen by electrolyzers.

In the *scenario concerning environmental impacts* hydrogen is introduced to the energy system in order to make efficient use of renewable energy and thus reduce the emissions of carbon dioxide. Wind energy in large amounts is introduced together with electrolysis and biomass gasification for hydrogen production from excess electricity and synthetic gas. In order to gain a maximum environmental benefit, hydrogen is used in the transportation sector substituting diesel, or for producing electricity and heat in fuel cells in centralised plants substituting coal.

Figure 1 shows the distribution of the energy resources used in the three different scenarios compared with the basic scenario. Furthermore, the figure shows the emission of CO_2 in the scenarios.

The conclusion of the project is that hydrogen seems to be a realistic energy carrier in the future Danish energy system. From an environmental as well as economic point of view the introduction of hydrogen in interplay with renewable energy technologies can be attractive, where the hydrogen is utilised in the electricity or transportation sectors.

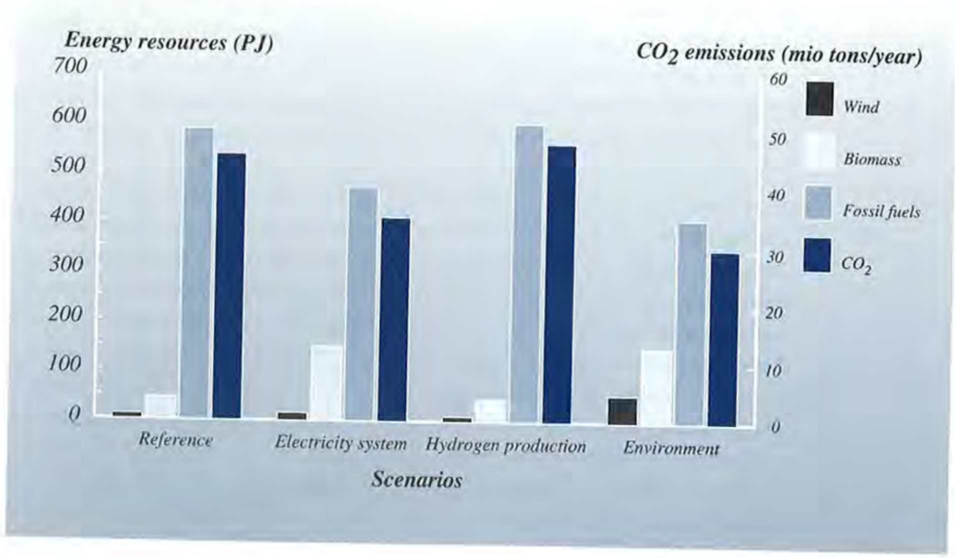
Combined cycle plants for coal or biomass gasification in combination with hydrogen production can be attractive and allow substantial wind power integration. The combined-cycle plants can operate as a buffer for the wind power, while hydrogen is produced from the synthetic natural gas in surplus.

Very large amounts of hydrogen may be stored in flushed caverns in salt domes, an economical and technically attractive way to store the hydrogen.

From an economic and environmental point of view hydrogen in centralised fuel cells or as a fuel for vehicles are the most attractive of the utilization methods. Also regarding safety the best of the analysed options to utilize the hydrogen is in centralised fuel cells or as a fuel for regular service in the transportation sector.

As a continuation of the project it is recommended to investigate the costs of the technologies in detail, as the costs mentioned for introducing the hydrogen technology

Figure 1. Energy resources and CO_2-emissions in scenarios for the Danish energy system year 2030.



are those for the single technologies and not for the total operational system. This may change the picture economically for the introduction of hydrogen as an energy carrier in the Danish energy system.

Furthermore, detailed analyses of hydrogen in vehicles and other practical experiences are important in order to estimate the potential for hydrogen as a fuel in the transportation sector. An analysis of the infrastructure (filling stations, distribution to the filling stations etc.) is very important.

Large-scale application of renewable energy technologies

Large-scale utilization of renewable energy in the future Danish energy system is analysed in a project carried out in collaboration with The Test Station for Wind Turbines, at Risø, and the utilities ELKRAFT and ELSAM. The project is supported by the Danish Energy Research programme.

The main question addressed in the project is, whether technically well-functioning electricity supply systems that are capable of providing the same quality of electric service as exists today can be developed on a timescale up to year 2030, based mainly on fluctuating electricity inputs from the renewable energy sources such as wind power, photovoltaic, wave power and biomass.

A scenario for the development of society at large is assumed, including the setting up of fundamental assumptions for the analysis. This scenario is called the "Ecological society". Defined here, this mainly implies for the energy sector an assumption of a persistent political willingness to promote energy conservation, utilization of renewable energy resources and reduction of pollutants and CO_2-emissions.

Within this scenario strategies are developed for energy conservation and energy supply. The analyses focus on the years 2005 and 2030, medium and long term, respectively. On the demand side the results of detailed assumptions on, e.g. economic growth and energy conservation are a total electricity demand close to today's level during the period, whereas heat demands in the CHP-system are expected to fall 40-50% during the period.

In the "Ecological society" the goal is to achieve a renewable energy utilization covering 75% or more of the expected Danish electricity demand in year 2030. A mile stone towards this goal is to reach a 25% coverage of the electricity demand year 2005 from renewable energy sources. Three energy supply strategies for utilizing renewable energy technologies and support technologies have been set up. Two strategies put main emphasis on wind power and biomass utilization respectively and the third strategy combines these two.

An assessment of the development of wind technology has been carried out. Improved design and efficiency are expected to reduce the specific cost of electricity from wind turbines by about 25% during the period. The unit size of typical mass-produced wind turbines is expected to increase from about 0.5 MW as seen today to about 2.5 MW in year 2030, and the future wind turbines are expected to operate at maximum efficiency over a wide wind speed range utilizing variable speed and active pitch control.

Figure 2 shows the fraction of wind energy produced that can be consumed directly in the present Danish electricity load profile (energy in phase). If the residual supply system is included a number of system constraints result in increased electricity overflow.

The main new technologies introduced in the "Ecological society" are biomass gasification and combined cycle plants on the short-to-medium term time scale. Gas technology is expected to play an important role in the future energy system, where high energy efficiency and system flexibility are essential. On the medium-to-long term, highly efficient fuel cells in large scale are expected to become available for the energy system.

Based on such technologies an energy system can be expected to yield high biomass utilization efficiencies. Furthermore, such a system can have high regulation capability, which is essential for the integration of large-scale wind and solar power production. Solid oxide fuel cells (SOFC) in reverse mode can utilize excess electricity from e.g. wind power in periods of high wind speeds and produce oxygen and hydrogen, which can later be used in the CHP-system, e.g. in gasification processes and in fuel cells.

The strategies form the starting point for technical calculations that specify system configurations in detail. Annual hour by hour time series measured in 1992 at four locations in Denmark are used as a basis for simulation of the wind power production. Installed capacity and energy conversion are described for the involved technologies and the equipment for electric regulation necessary to assure the required quality of electricity supply is described.

On this basis, technical-economic and environmental model calculations are carried out for the total Danish energy system. Consequences of the strategies are calculated to yield energy consumption, emissions to the environment and the economic consequences. These are compared with other studies of long-term development strategies for the Danish energy system.

The robustness of the strategies for a transition towards large-scale utilization of renewable energy in the electric system is tested on a medium-term basis. Two further scenarios for the development of society at large are formed as a basis for this test. In short these scenarios can be characterised by their names: "The consumer society" and "Europe in crisis". The strategies formed within the "Ecological society" are thus analysed when subjected to altered basic preconditions as determined by the two alternative scenarios.

At present definition, description and quantification of the scenarios and the analyses on the demand side of the energy system including future demands for generating capacity have been completed. Furthermore, the data preparation work, assessments of technological developments and analyses on the existing heat and power supply system have been completed. Decommission time tables for the CHP-system have been completed and the strategies for the system development have been formed and the detailed technical supply system simulations are ongoing.

The project will be finalised in mid.-1994.

Publications in 1993: 43,52,53 and 54

Lars Henrik Nielsen and Lotte Schleisner

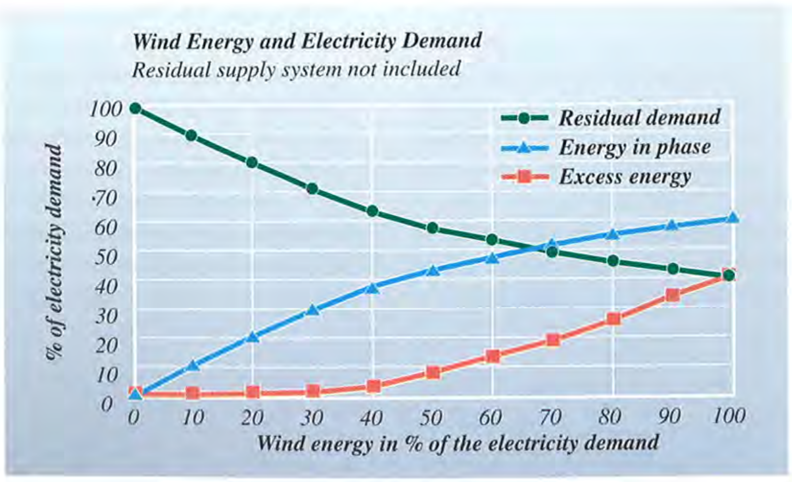


Figure 2. Wind energy and electricity demand.

Integrating Top-Down and Bottom-Up Modelling

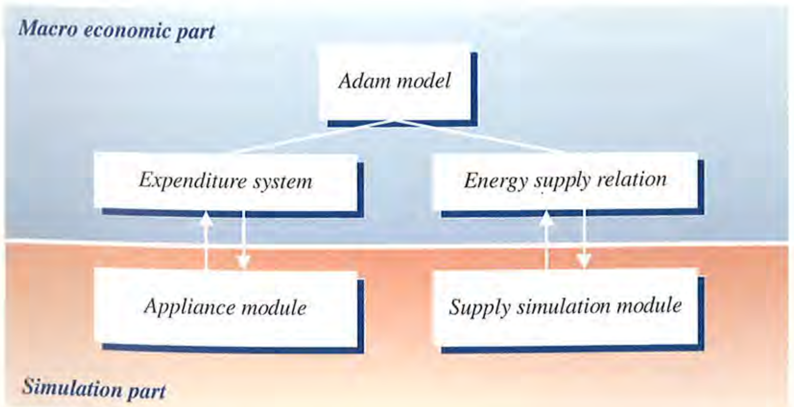
The integration of top-down (macroeconomic) models and bottom-up (simulation) models is internationally considered to be a highly important issue. Several attempts have been carried out with limited success. Some have concentrated especially on the supply side, linking a fairly simplistic macro-part to a highly developed simulation model for the energy supply system (i.e. the Markal-macro model); others have taken the opposite viewpoint introducing simple relations for the energy supply in a macro framework.

The BRUS energy system scenario model, developed by Risø, was used for the calculations performed in the Danish Energy 2000 action plan. The main macroeconomic assumptions were given by the Danish macro-model, ADAM (Annual **D**anish **A**ggregate **M**odel), the official forecasting tool in Denmark used by the Danish Ministry of Finance. In connection with the Energy 2000 plan the first attempts were made to introduce the outcome of the BRUS-model into the ADAM-model, to illustrate the macro-economic consequences of the changes in the energy system, but no comprehensive analysis was carried through.

Linking BRUS and ADAM

The present project is supported by the Danish Energy Research Programme and it is carried out in a cooperation between Risø National Laboratory and The Danish Ministry of Finance. The project was initiated in 1993 and is expected to be finalised in 1995.

The aim of the work is to link some of the important modules in the BRUS-simulation model with the macroeconomic ADAM-model. In the first phase simplistic versions of two modules in BRUS are introduced: the module determining the use of electricity for household appliances, and the one modelling the combined heat and power supply, including district heating plants and renewable energy technologies. The approach is shown in the figure.



Linking modules from the BRUS-scenario model to the macroeconomic ADAM-model.

The module calculating the use of electricity for household appliances is based on a Vintage-stock-model, representing the most electricity-intensive appliances. The relation from the ADAM-model for the household consumption of appliances is linked to the Vintage-stock-model, determining the annual purchase of appliances. Given the annual replacement the total stock of appliances is determined. Assuming coefficients for electricity use for each appliance, the total electricity consumption is calculated, thus replacing the corresponding relation in the expenditure system in the ADAM-model.

At present the energy supply system in the ADAM-model is determined mainly by exogeneous parameters. In the project a planning module is developed that takes into account the development plans for the utility sector. The most important novelties of this module are to calculate explicitly the investment for the development in the electricity and heating areas and to replace the existing exogeneous relation for import of fuels for CHP-supply with a much more detailed modelling.

Introducing these two modules in the ADAM-model makes it possible to carry out analyses of more details within this part of the energy system, i.e. to calculate the consequences of changing the energy supply system towards less CO_2-emitting fuels as natural gas and biomass.

Poul Erik Morthorst

Environmental Planning and Uncertainty

Environmental planning has become an important task for regulating and controlling socially related activities both nationally and internationally. Acidification is one example of an environmental issue in which regulation is sought through the control of emissions arising from energy production and use. When such cause-effect relationships are analyzed the concept of *uncertainty* must be recognized. Uncertainty appears in connection with, e.g., measures, estimates and calculations (as components of a mathematical model) which form the basis for the formulation of plans for regulating aspects of pollution. Uncertainty is hereby considered a factor which can be explicitly expressed in terms of for example a numerical value. However, it is only a limited number of uncertainties that can be treated in such a way. The effects of human and political activities are often unforeseen and become a crucial aspect of environmental planning.

The overall purpose of the project entitled "Environmental Planning and Uncertainty" is two-fold: to analyze the environmental planning activities, i.e., both the technical/scientific as well as the policy management aspects, in terms of the uncertainties associated with them, and to investigate how mathematical models are used in environmental planning. The project was finalized in 1993.

Planning

In order to concretize the research, the analysis was concentrated on three case studies on environmental planning. Each differed in terms of how scientific information has been used in environmental planning processes and in the way uncertainty was associated. Two national planning cases were selected: the Danish Water Action Plan (ratified 1987) and the Dutch National Environmental Policy Plan (ratified 1990). The former is an example of a planning process where uncertainties associated with both technical/scientific findings and policy management activities were disregarded. This was not the case of the Dutch National Environmental Policy Plan which was seen as one example of planning where uncertainty aspects were dealt with through methodological structuring of various tasks in the process.

The third case concerned the development of the European sulphur protocol for reducing acidifying emissions. This example showed that models can be used directly in the planning process in spite of limited actions taken to treat the inherent associated uncertainty.

Uncertainty

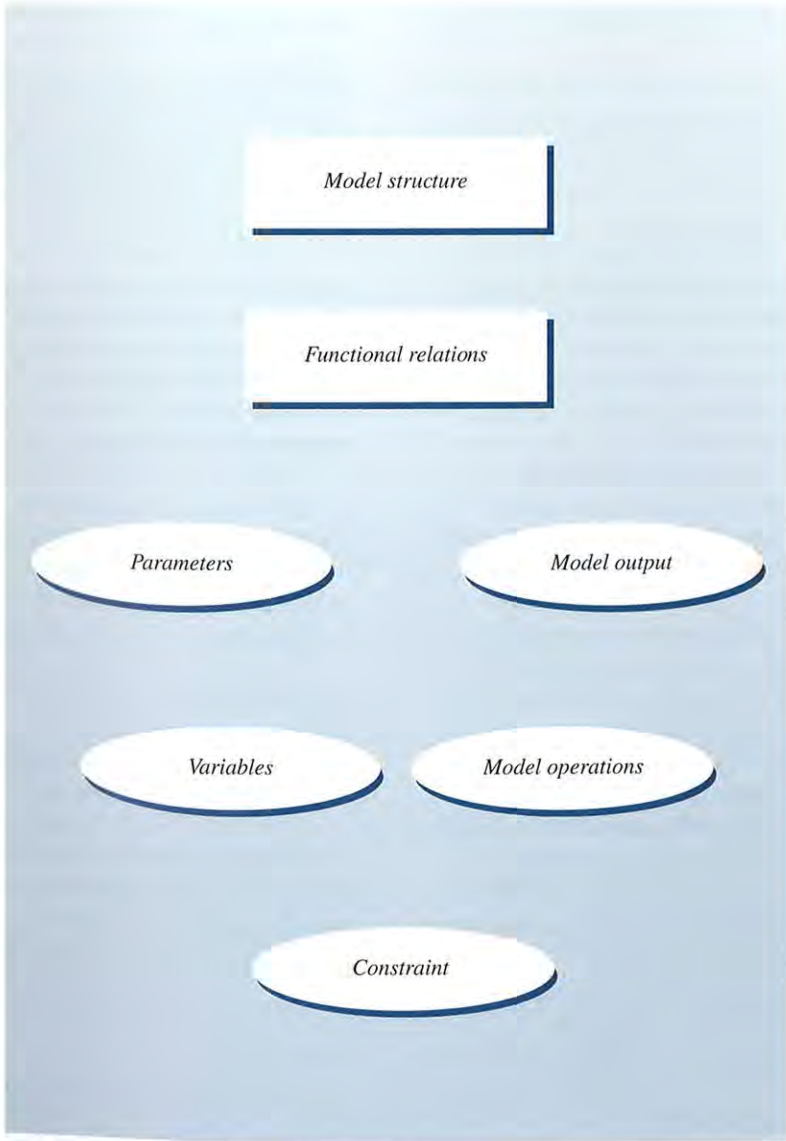
Accuracy and robustness are words closely connected with uncertainties in model calculations and results. One part of the project was devoted to identifying model factors that, individually or jointly, were decisive for ascertaining the accuracy or robustness of the results of model runs. These factors were referred to as uncertainty elements.

After studying the cases, it became obvious that a large number of model uncertainty elements can be identified. In the project, it was suggested that these aspects be classified into a hierarchical structure of uncertainty which shows the uncertainty elements and their mutual ordering as they are presumed to contribute to the total level of uncertainty of the model results. This hierarchical structure is shown in the figure.

The uncertainty elements associated with the modelling activity are closely connected with the components of a mathematical model. The model structure and functional relations (being mathematical equations) are placed in the boxes as the major elements for determining the accuracy of model results. Encircled below are the model inherent components, each being the contributing elements for the uncertainty of model results: parameters, variables, constraints, model operations and model output itself. These elements are less decisive for determining the level of uncertainty of model results than the model structure and functional relations.

No matter what system is to be modelled, a model will always be a simplification of reality. By defining the model structure, deviations from the real-world system appear. In practice this means that the accuracy of the model is highly dependent upon the methodological approach used for describing the system as well as the boundaries selected to limit the description. This does not however necessarily imply that one methodological approach, such as is traditionally used in economy or engineering, is better than another, but only that there can be differences in the model results resulting from these selections. The above comments also apply to the functional relations (mathematical equations). Mathematical equations for system description can naturally be selected in numerous ways with more or less mathematical sophistication. The accuracy or uncertainty of model results are again closely correlated with these selections.

The uncertainty elements and their mutual ordering as they contribute to the total level of uncertainty in modelling and research activities.



Given the frames of the model, the encircled elements contribute equally to the level of uncertainty. First there are those constant parameters unchanged by model calculations as, for example, the sulphur content of a fuel used for energy combustion. Then there are the variables which are values that are changed through the model calculations. One example of this is the lifetime of a power plant. Thirdly, there are the constraints, starting values or limitations of the validity of the mathematical equations. The model operations which basically are the translation of the mathematical equations and terms into numerical modelling terms can be mentioned as a fourth element. And lastly, the model output and how it is presented and understood can provide information on the level of uncertainty that exists.

Dealing with uncertainty

Most mathematical models are accompanied by analyses aiming at determining the accuracy of the calculations made when using the model (uncertainty analyses and evaluation; the latter concept is to be understood as a broader concept where uncertainty analysis, validation and verification of the model are performed). Uncertainty analyses commonly aim at quantifying the uncertainties associated with model parameters, variables and model output. If one compares the uncertainty elements with those depicted in figure 1, it is obvious that because of the difficulties involved only a small fraction of possible uncertainty elements are dealt with.

In the project it was discussed how uncertainty elements as those mentioned above can be dealt with in methodological terms. Considering the uncertainties in modelling uncertainties, it is evident that the evaluation of models in traditional terms is not sufficient to insure that uncertainties are dealt with, and can be dealt with in a comprehensive and thorough way as is necessary when models are used in planning. As a major result of the project a broader evaluation concept was suggested from which the accuracy and robustness of the model is only a small part of a more thorough analysis of how well the model adapts to the problem at hand and its specific use.

Publications in 1993: 73 and 75

Lene Sørensen

External Effects in Utilising Renewable Energy

It is generally recognized that externalities from energy production can constitute an essential part of the total costs. If these external costs to society are not included in the market price, many energy investments may be based on biased assumptions.

The main objective of the Danish project on externalities is to identify and describe the externalities of relevance in relation to renewable energy technologies. If possible, these externalities should be quantified and monetized.

The project which was started early 1993, is initiated by the Danish Council for Renewable Energy and is to be finalised mid-1994. The first part of the project pays special attention to the theoretical aspects of the definition of externalities in relation to the energy system. The second part deals with more exact findings on externalities in connection with renewable energy, which in this project is biomass and wind energy, compared with the substituted non-renewable energy sources.

The general economics of externalities

The introduction of external effects or externalities into the economic theory started in the beginning of the twentieth century through the further development of welfare theory. In connection with the definition of externalities, Pigou defined the social net production and private net production, factors that are inseparable from external effects. The phrases are often, respectively, called the social and private costs.

There are several definitions of external effects. The one used is:

An external effect will be said to exist whenever "economic activity in the form of production or consumption affects the production or utility levels of other producers or consumers and the effect is unpriced or uncompensated". (Dasgupta and Pearce).

The first condition is the interdependence condition, and the latter is the non-price condition. Both conditions must obtain for an externality to exist.

The project mainly deals with externalities linked to the environment, but a number of external effects are not directly connected to environment (for instance, externalities like infrastructure and education).

Evaluation of the external effects can be divided into two major parts. The first part is calculation of the quantities of SO_2, CO_2 etc. emitted from various energy production technologies. The second part is the monetization of the effects of the quantities.

Monetization makes it possible to achieve two purposes: to establish the real price of the good, and to make comparisons between different types of externalities, which otherwise may be difficult. Through establishing the real price of the good, actions can be taken to ensure that price via taxes and subsidies.

Monetization is in many respects difficult, because it involves qualitative valuations and uncertain data. In reality it will be impossible to quantify and monetize all existing externalities, and therefore the results often represent a minimum of the total externalities in connection with the given energy form.

Externalities in relation to renewable energy

The use of renewable energy technologies is to be seen in close relationship with the existing conventional energy system. Therefore, it is important to identify not only the externalities connected to the use of renewable energy technologies, but also the externalities in relation to the part of the energy system that is substituted by renewable technologies. In the project two case studies are included:

- A biomass case, where a combined heat and CHP power plant fueled by biomass substitutes a small-scale natural gas-based CHP plant.
- A wind energy case, where wind turbines substitute a coal-fired condensing plant or a CHP plant operated in condensing mode.

Quantification of externalities in relation to the above-mentioned production alternatives is done according to two levels:

- The fuel cycle, split into production, transportation and conversion of the fuel into electricity and possibly heat.
- the plant construction cycle.

For each component in the fuel cycle a methodology for analysis is used giving the following steps:

1. identification of the *burden* (e.g. emissions of SO_2)
2. dispersion of the burden (atmospheric)
3. *impact* (acid rains)
4. *consequence* for nature or human beings (damaged trees).

Analysing each of these steps makes it possible to construct a branching structure. A quantification is carried out for all externalities mentioned at the lower level of the figure and monetized values attached to each.

Concerning the plant construction cycle, this is dealt with using input-output techniques, separating the most important parts of the plant.

Main result

The main result of the project is the development of a comprehensive method to assess externalities in relation to renewable energy technologies and the technologies they substitute. This method is tested in the two case studies for comparison of the energy production costs with external costs included at the present state of the energy system.

Similarly, the costs will be compared in a future year (2010), taking into account a development with and without the use of abatement technologies at the combustion plants. This will show not only the magnitude of today's existing externalities, but indicate a possible development of the external costs in the future.

Poul Erik Morthorst

Emission Inventories

There is a collaboration among many international organizations and conventions about methods for and implementation of emission inventories. The CORINAIR database of EU for emissions to the air is used to prepare the reports to the international organizations from all European countries. In this way a consistency in the international emission statistics and modelling is secured. The CORINAIR database forms an important part of the basis for the European Environmental Agency. The inventory work for Estonia, Latvia and Lithuania is coordinated by Risø for EU.

Risø participates actively in this work and has the responsibility of the Danish inventory in collaboration with the National Agency for Environmental Protection. The Danish inventories prepared by RISØ form the basis for discussions on emission reductions in the international forums, e.g. the Framework Convention on Climate Change (for greenhouse gases) and in ECE where an increase in the targets for reduction of the SO_2 and NO_X emissions are discussed.

Risø is chairing the ECE expert panel on maritime emissions. Emissions from the international sea transport are discussed intensely in IMO (the UN international maritime organization). Risø is here participating on behalf of EU. At the present moment the upper limit on sulphur content in the fuel is as high as 5%. An effort is made to introduce a global maximum of 3.5%, supplemented with a maximum of 1.5% in regional seas such as the North Sea.

The work on emission inventories creates a detailed platform in which to make decisions on limiting emissions to the air. Also model calculations on the future developments in the size of the emissions are important. A conference on this subject was thus held at Risø in 1993.

The table shows some of the final results from calculations carried out at Risø for the National Agency for Environmental Protection, all emitting sectors are included: electricity production, space heating, industrial processes, all kind of transportation and also emissions related to other activities than energy combustion. The emissions are disaggregated into a number of sectors consistent with the CORINAIR activity sectors. The emissions from power plants, e.g. from the production of electricity and combined heat & power, vary from year to year because Denmark in some years has a large electricity import. Therefore a correction is made , where the emission is calculated as if it were produced under average conditions at Danish power plants. The power plants are the main emitters of CO2 (49%) and SO2 (70%). The emissions from district heating plants include those from the combustion of biomass and refuse for which CO2 has to be subtracted again because it is reabsorbed by the growth of new biomass. Industrial combustion include the emissions from the refineries whereas the combustion & flaring of natural gas on platforms in the North Sea is included in extraction and distribution of fossil fuels together with the emissions from the natural gas network and coal storage.

The transport sector is the major emitter of NO_X (57%), CO (73%) and of NMVOC = non-methane volatile organic compounds (55%). The emission factors for this sector are based on calculations with the COPERT-model for the transport sector which is a background model for the CORINAIR-model The modelling of the transport sector for Denmark with COPERT was done by Risø and a benchmark analysis resulted in a calibration with the road transportation emission model at the Technical University of Denmark. The emissions for road transport were calculated separately for passenger cars, light duty vehicles and heavy duty vehicles because the emission factors can vary up to a factor of four between these classes of vehicles.

A major effort in the latest inventory prepared at Risø has been defining the methodological activities in the sector that combines other mobile sources. This sector include sea-traffic between Danish ports, landing and take-off (LTO) cycles for all aircraft in Danish airports and off-roaders such as tractors, harvesters, trucks and earth-moving equipment.

The emissions from international sea-traffic and from the fuel used by aircraft when they have exceeded a height of 1000 m is shown in the bottom line International transport. The fuel used in the LTO-cycles was calculated based on information collected for the different types of aircrafts landing at Danish airports and their engine characteristics. The remaining jet-fuel sold in Danish airports was then allocated to the sector international air transport. All the energy-related emissions in the Table are based on an improved version of the energy statistics from the Danish Energy Agency specified by Risø. In order to make it possible to calculate the emissions from the off-roaders gasoil and dieseloil were disaggregated since mobile and stationary sources have very different emission factors. This is especially important for the NO_X-emissions from off-roaders which account for about 10% of the total emissions.

Sector	CO_2	SO_2	NO_X	CH_4	N_2O	NM-VOC	CO
Power plants	26341	130.0	82.0	0.45	0.82	0.45	3.0
District heating plants	4260	16.0	7.0	0.50	0.13	0.68	39.9
Residential burners	7795	8.4	5.7	6.55	0.20	9.31	151.3
Industrial combustion	7921	27.4	14.5	0.73	0.21	0.85	4.2
Road transport	9356	6.6	103.7	1.87	0.36	101.97	565.1
Other mobile sources	4138	12.1	60.7	1.03	0.14	13.37	28.7
Combustion of biomass & refuse	-5091						
Non-combustion	2913	0	5.7	743.43	19.42	79.84	35.4
Electricity import	3174	16.0	11.0	0.05	0.10	0.05	0.4
Total domestic emission	**60807**	**216.4**	**289.9**	**754.62**	**21.38**	**207.50**	**827.9**
International transport	4167	36.3	64.2	0.1	0.15	2.49	16.4

Emissions from Denmark in 1992

The major part of the emissions from the six sectors not related to combustion processes is based upon our report "Danish Budget for Greenhouse Gases" from 1990. Only two of the major emissions of CH_4 were revised: the emissions of CH_4 from landfills have been lowered from 310 to 120 kt and the CH_4 emissions from coal storage is now estimated to be 2.7 instead of 16 kt.

Jørgen Fenhann and Niels Kilde

UNEP Collaborating Centre on energy and environment

UNEP Activities and Collaboration with Other International Organisations

The UNEP Collaborating Centre on Energy and Environment, as a key part of its general mandate, provides substantive support to UNEP - the United Nations Environment Programme. This support is especially directed towards the Energy Office, but close relations are also maintained with the Global Environment Facility (GEF), Climate, Economics and Environment units, and the regional offices.

On a more limited scale the Centre also cooperates with other UN and international organisations.

The ad-hoc support and collaboration with the Energy Office can generally be divided into 3 categories:

Project support to the Energy Office

This involves all phases of a typical project from establishing the basic idea or rationale through preparation and institutional arrangement to monitoring and follow-up.

Typically, all the activities are undertaken in direct collaboration or close interaction with staff in the Energy Office. Two projects

Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China

and the new

LEAP/EDB development activity

were approved for UNEP funding in 1993. For both projects the Centre was instrumental in setting up the activities and will assume an active role in the implementation. A new activity focusing on urban energy development is under development and is expected to start early 1994.

In connection with the Environmentally Sound Energy Development - India Pilot Project, the role of the Centre is seen more in terms of monitoring the activities of the implementing organisation the Tata Energy Research Institute and in collaborating on aspects of environmental data like emission factors, which through the EDB programme can be utilized also in other developing country contexts.

Representation and position papers

These types of activities have bee undertaken at a number of different occasions. One example is UNEP's participation in the activi ties of the World Energy Council (WEC) where Centre staff has been involved in the Committee o Renewable Energy, which published its final report in the middle o the year. From 1993 Centre staff also represents UNEP in the permanent Developing Countries Committee. In relation also to WEC the Centre prepared a revie of the recent report of WEC Com mission report "Energy for Tomo row's World"; this review will be published as a statement by the Executive Director of UNEP in a forthcoming WEC Journal.

Information support

This covers on a broad basis activities of a direct ad-hoc type such as providing background information to meet external requests or more substantive input to internal programme activities, inter-agency coordination, etc.

Activities with other UNEP programmes

Other more specific activities in 1993 have included, for example, participation in the UNEP Governing Council as observer and during the council session convening a joint presentation of UNEP's and the Centre's activities to interested national delegates.

Another major activity with UNEP HQ is the collaboration with the GEF office where the Centre assists with reviews of projects in the global warming priority area. Projects submitted by the other GEF partners for possible funding are sent for review and commenting and in many cases a UNEP position statement is developed in close collaboration with the area coordinator in the GEF office.

The collaboration with the Climate office is centred around the GHG abatement costing project. Since this project so far essentially has been an energy – environment activity with focus on CO_2 it has been very easily integrated in the Centre's general programme of activities.

A new programme on Economics and Environment was established in UNEP in 1993 and is expected to become a significant new activity area. Close coordination is maintained with this programme given the nature of the links to economic issues present in many of the Centre activities and especially in the GHG abatement costing project.

Cooperation with other international organisations

In addition to the UNEP activities, the Centre has formal or informal links with a number of other UN agencies, the World Bank and various international and national agencies and research institutions. With the involvement in GEF activities, contacts have been established especially with the other partner institutions UNDP and the World Bank. Centre staff has been invited to present papers on several meetings and workshops related to GEF activities.

A special collaboration has been initiated with the GEF Administrator's office and the**PR**ogramme for **IN**cremental **C**osts to the **E**nvironment – PRINCE. The first result of this collaboration will be a major international conference in June 1994 convened by the Centre with support from PRINCE, Danida and UNEP.

Some of the key project related national collaborators are mentioned in specific activity descriptions in the following sections, but in addition it should be stressed that the Centre has strong relations with regional institutions and networks such as the African Energy Policy Research Network (AFREPREN), the Asian Energy Institute network, the Asian Institute of Technology and the Latin American Energy Organisation (OLADE).

John M. Christensen

Risø-R-724(EN)

Energy Environment Planning Programmes

The Centre has as its broad mandate to promote the incorporation of environmental considerations in energy policy and planning in developing countries. One of the ways this is being pursued is through direct collaborative activities with institutions in a number of developing countries.

In this section the substantive aspects of some UNEP funded projects are presented and the different functions that the Centre is fulfilling in relation to the different projects are outlined.

In addition to these UNEP financed projects the Centre is also undertaking other similar activities as part of its core work programme or through other external funds.

Environmentally Sound Energy Development – India Pilot Project

The India pilot project, which started in 1992 and will continue till the end of 1994, is attempting to identify energy development paths which minimize the impact on the environment and at the same time allow India to carry on economic activity which is likely to result in a 5% annual growth rate in GDP during the next two decades. The study aims at identifying the amount of investment that is required in the various key sectors to follow the path of minimizing environmental impacts.

This will also enable an assessment of the incremental costs which could be funded through international mechanisms, such as the Global Environment Facility in connection with the implementation of the UN Framework Convention on Climate Change.

The project was initiated early 1992 and is implemented with the Tata Energy Research Institute (TERI) as the supporting organisation under the control of a national steering committee chaired by the Ministry for Environment and Forests and an international advisory committee with UNEP and Centre representatives.

The role of the Centre in 1993 has mainly been to monitor project activities and collaborate with TERI on specific topics centred around environmental data especially getting specific emissions factors for India included in the Environmental Database hosted by the Centre.

Two meetings of the International Steering Committee were held during the year in Delhi at the Tata Energy Research Institute, The Centre represented UNEP in both meetings, and in addition to the formal meetings informal consultations were held with members of the various groups working on the project. The planning of the programmed future activities were also discussed especially relating to the workshops and other dissemination activities.

A status report was submitted to UNEP in early 1993 providing information on most aspects relating to current energy supply and use in India. It also includes partial information on the type of environmental impacts of energy supply and use in India. This report also contains an outline of a computerized data base that is being planned as a part of this study which would be made readily available to energy planners for carrying out similar exercises. Another report examining the preliminary findings of the project in the context of the new five-year plan was also published in 1993. Centre staff reviewed both reports and the reviews were used in the recommendations at the steering committee meetings.

Incorporation of Environmental Considerations in Energy Planning in the People's Republic of China

This project and the one in India are regarded as two key activities in UNEP's energy programme. The project has been under preparation for more than a year. The Centre has been working very closely with UNEP HQ in the whole preparatory phase where two joint missions were undertaken.

The project objectives follow UNEP's general mandate in the energy area, which is to promote integration of environmental criteria in national energy policy and planning. Specific aims are to strengthen national and regional institutional capacity in the area of energy environmental analysis and to promote policies that reduce energy related environmental emissions.

The project will provide a broad overview of the national energy development situation and develop alternative national energy scenarios including analyses of implementation options and establishment of a plan of action.

This national activity will in part be based on more detailed case studies for Beijing City and the Guangxi Autonomous Region developed in close collaboration with the local authorities and institutions.

The project implementation organization comprises a National Coordination Committee with representatives from the most important national committees and institutions, a Management Committee with the directly involved institutions, and a Project Office to coordinate and plan the many detailed project activities.

The project document between UNEP and the Chinese Government was signed in June and the National Environment Protection Agency (NEPA) is the implementing organisation.

Following the meeting in June, NEPA initiated the first activities under the project and prepared a workplan and time schedule for all planned activities with the highest level of detail for work in 1993.

A status meeting involving UNEP and Centre staff was convened mid-November where the plans were discussed, revised and agreed upon.

The detailed work plan for the project includes a first national workshop, which was convened with the support of Centre staff (see picture above). This workshop was held from 2 to 14 December 1993 for 40 technical staff members of the central and regional teams. The purpose of the workshop was to equip the project personnel to:

- follow a common methodology in collection, collation, analysis and interpretation of data on energy supply and use and on associated emissions and other negative environmental impacts, and
- evaluate and estimate in economic terms the cost of negative environmental effects due to current energy production and utilization patterns in China.

The Centre contributed with data and analysis expertise especially in relation to integrated energy environment assessment and interpretation of results.

The collaboration between the Chinese project team and the Centre will be further expanded in 1994 where it is planned that some of the core project staff will visit the Centre for an extended period.

Environmentally Sound Energy Options for Africa

This collaborative effort with the African Energy Policy Research Network (AFREPREN) and the Foundation for Woodstove Dissemination was finalised in 1993 with the book "Environmentally Sound Energy Options for Africa" published by Zed Books, London.

The book has been distributed widely especially in the African region, but there has been global interest. In addition the activity has had several impacts on the work programme of the network in terms of focusing more on environmental aspects in the different theme groups. Follow-up activities are under discussion and early in 1994 a regional seminar will be organised by AFREPREN to initiate a new African Energy Initiative with the aim of developing an Environmentally Sound African Energy Charter.

A specific follow-up activity, finalised by the Centre and the University of Twente in 1993 for the Swedish Agency for Research Cooperation (SAREC), was an evaluation of the whole AFREPREN network activity from 1989 to 1993 sponsored by SAREC. The overall aim of the evaluation was to broadly assess the achievement on the three broad objectives for the AFREPREN programme. Stated briefly this included looking at research quality, quantity and relevance aspects, research capacity building and the overall policy impacts.

The final report was presented to SAREC and the network steering committee in April. The evaluation found that significant "value" has been obtained and the operation and organisation of the network has generally been very efficient with a relatively unique record for the region. Based on this broad assessment the conclusion was that both the funding level and the results have been reasonable and commensurate. A number of proposals were made in the evaluation for improving network management and especially increase the policy impact aspect of activities.

A number of decisions were made by the network steering committee already at the meeting in April to implement some of the key recommendations, others will be introduced gradually.

Energy environment planning in Argentina

A collaborative project is being undertaken with the Instituto de Economía Energética (IDEE), Argentina. The project extends the Centre's collaborative activities in Latin America, which are generally aimed at assisting energy planners in the region to develop tools and criteria for assessing environmental impacts and macroeconomic effects of energy policies.

In the first stage of a planned long-term collaboration with IDEE, the project will focus on a critical analysis of present policy criteria and on a first approach to the formulation of new criteria and planning methods, and their application to the Argentine context.

IDEE is active in research, post-graduate training and technical assistance in energy economics and planning. In this sense, IDEE constitutes the appropriate institutional frame for developing energy environment planning methodologies adapted to the needs of Latin American countries.

One of the institute's major regular activities is a three-month training course for Latin American energy professionals: "Energy Economics and Planning". The Centre contributed to the course in 1993 with a session on cost analysis and environmental impacts of energy development, and a presentation on LEAP/EDB and simple spreadsheet models.

A draft report of the first stage collaborative project was prepared by the end of 1993 and the final version will be published in 1994.

Publications in 1993: 11, 33 and 37

JOHN M. CHRISTENSEN

The UNEP Greenhouse Gas Abatement Costing Project

Background

The UNEP project on developing a common methodological approach for assessing the costs of limiting greenhouse gas emissions was initiated in 1991 to gain a better understanding of the subject, and help lay the basis for national studies of the economic issues which would be accepted as objective, accurate and comparable between countries.

The first phase of the project consisted of detailed studies of the underlying issues in estimating abatement costs and a small set of preliminary national studies. These country studies established the status of analysis and data in the countries concerned and illustrated the practical issues raised in embarking upon abatement cost studies in widely diverse countries. This work was described in the report of Phase One of the project in 1992.

Development and testing of the methodology

On the basis of the first phase of the project, a methodological approach was developed and tested in ten country studies carried out by national teams from Brazil, Denmark, Egypt, France, India, the Netherlands, Senegal, Thailand, Venezuela and Zimbabwe. The central project team led by the UNEP Centre was responsible for formulating the guidelines and coordinating the country studies. The approach was improved in an iterative fashion in conjunction with the national teams, particularly through four project workshops, and through application of the guidelines in their national studies.

The proposed methodological framework for national GHG (greenhouse gas) abatement costing comprises three elements:

1. key concepts and terminology,
2. common quantitative assumptions, such as international fuel prices, test discount rates and reduction targets, and
3. analysis structure comprising:
   - country review (background and existing studies),
   - definition of reference scenario, identification and ranking of abatement options,
   - construction of abatement scenario,
   - macroeconomic assessment,
   - subsequent evaluation (political, social etc.)

Reference and abatement scenarios

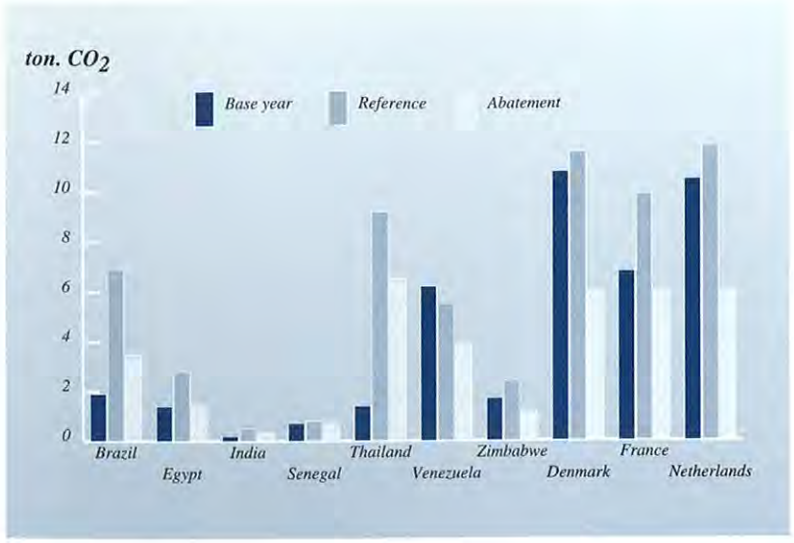
The cost of GHG abatement is defined in terms of the difference between a *Reference Scenario* and an *Abatement Scenario*. Each scenario consists of a consistent description of a country, particularly its energy system and GHG emissions, over the period of the study, typically until 2030.

In the project, which aims at comparable assessments of abatement cost, it was attempted to establish a comparable framework for scenario definition. While each country's future scenarios will inevitably be unique, the comparability of studies is enhanced by following similar paths and sets of assumptions, for example with regard to world fuel prices and average global economic development.

The trends in CO_2 emissions projected in the ten country studies show great variation. Differences between the emission growth rates among countries reflect differences in development levels, assumptions, economic structure etc. In particular there is a marked difference in the projected emission trends between the group of developing countries and the three industrialized countries. In spite of these differences, the common structure, terminology and background assumptions in the project make it possible to explain and understand the differences and similarities. Much of this explanation depends on the details of energy-sector developments in the country studies.

Calculations from reference scenarios for the seven developing countries reveal that the total carbon dioxide emissions from the group will increase from 750 million tonnes in the base year to about 3500 million tonnes by the end of the period in 2025-30. The high abatement scenario reduces CO_2 emissions to 2100 million tonnes. This corresponds to a 40% reduction in CO_2 emissions from baseline, but still represents almost a tripling of emissions. The full 50% was not achieved in the aggregate because for various reasons feasible solutions at this level of reduction from baseline were not attained in a few of the countries.

Figure 1. Calculated per capita CO_2 emmisions in the base year (1990) and end year (2025/30) for reference and abatement scenarios.



The country studies show substantial differences in terms of the amount of CO_2 emissions per capita (Figure 1). For example, the Thailand reference scenario projects a six-fold increase in per capita emissions, while in Senegal and Zimbabwe per capita emissions remain roughly constant. On comparing the results in absolute terms we find significant differences between countries: CO_2 emission levels per capita in Thailand are expected to exceed those of India by more than 20-fold and reach the levels of the industrialized countries by 2030.

Abatement costs

Following the project guidelines, country teams estimated short and long term abatement costs for reduction targets from baseline between 12.5-25% in the short term (2005 to 2010) and 25-50% in the long term (2020 to 2030), where cost is defined as direct cost including investment, operation and maintenance, and fuel costs.

Figure 2 shows marginal abatement costs for most of the participating countries in the long term. The cost curves for developing countries exhibit a number of similarities. A particular feature is the large potential for negative cost abatement options, amounting to up to 20% reductions from baseline based on marginal cost in 2005/10 and about 35% in 2020/30. The curves are also similar in shape: the first part of the cost curve indicates a very low abatement cost, followed by a long interval in which abatement cost falls within a narrow range between -\$10 and +\$30 per tonne CO_2 reduced.

The abatement cost estimates for industrialized countries are more varied. The Danish results are similar to the majority of the developing countries, while the Netherlands and France estimate much higher abatement costs.

All the studies show a general similarity, namely that the least expensive part of the cost curve contains energy end-use savings in industry and/or households. For the developing country studies in general, the profitability and possible penetration rates of such energy-saving end-use technologies are closely linked to general macroeconomic development and possible energy price adjustments to world market prices. This means that some of the least expensive GHG reductions will overlap with more general investments in efficiency improvements that are profitable without taking GHG reductions into consideration. Consequently, a cost-effective GHG reduction policy cannot be

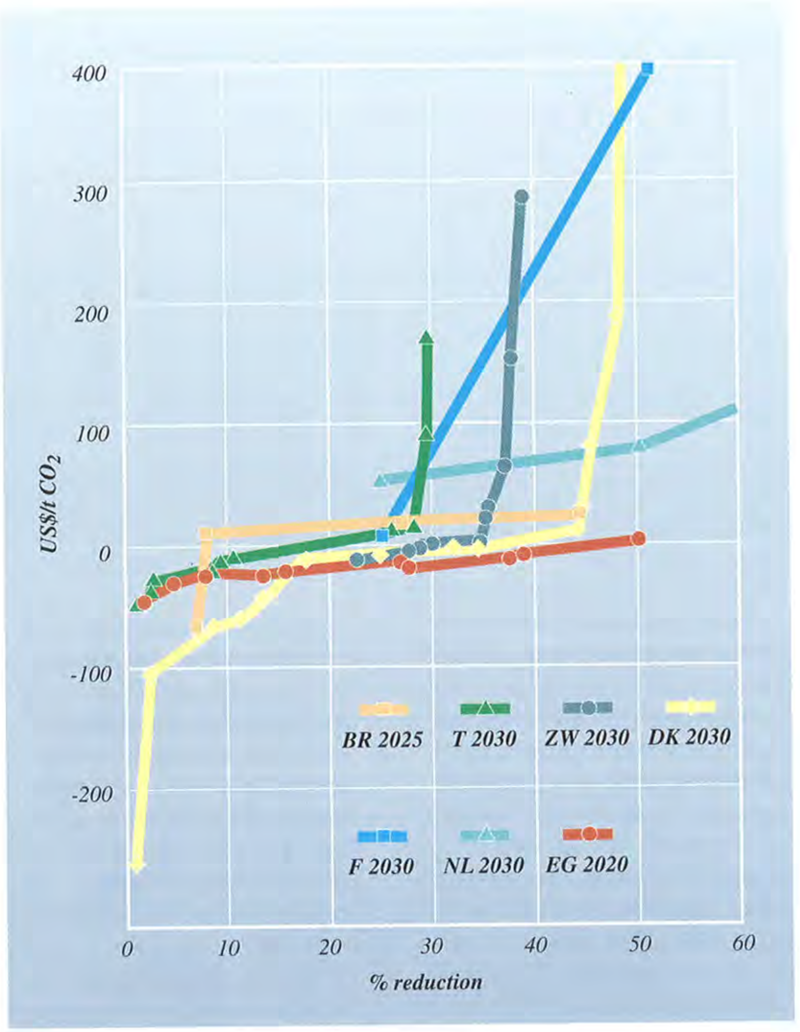


Figure 2. Marginal abatement costs for emmission reductions in 2020/30.

carried out without investigating more general efficiency problems in the existing energy system and the economic system as a whole. Removal of general inefficiencies in the economic system must be in the national interest, and at the same time GHG emission reductions should be implemented on the basis of a baseline, which is defined according to a plausible efficient economic development.

Conclusions

One of the primary aims of the project was to develop a methodological approach for carrying out comparable country costing studies. It is difficult to find a simple absolute measure for the comparability between different studies, and thus to judge the success of the project in achieving this aim. The measure of success of the guidelines lies more in the *transparency* and *detailed documentation* of the studies, and in the degree to which a consensus was achieved among such a broad group of researchers and planners, spanning ten countries and differing interests, together with the members of the central project team and advisers.

An important outcome of the project is the extent to which the subject of GHG abatement costing has been brought to a higher level of awareness and expertise within the participating teams, both in the developing and industrialized countries. Through the discussions, the formulation and revision of the guidelines, and the execution of the country studies, all parties have become more aware and able to deal with the issues in a manner which can be understood, and hopefully accepted, nationally and internationally.

With the completion of the second phase of the project, a comparable methodology has been established and a number of important results obtained for the participating countries. The level of detail of the results and their reliability clearly vary from country to country, depending on the availability of data, the sophistication of analysis tools, and the amount of resources which could be applied to clarifying costs and potentials of abatement options. The study revealed a wide range of areas where detailed further work is required, both within the CO_2 from energy context already covered, and non-CO_2 and non-energy emissions.

The ten country studies involved in the project achieved by no means the same level of detail in their analyses of GHG abatement. Some countries joined the project at a relatively late stage, while others had a long tradition of similar work and expertise which could be built on. The country teams also used different models, and had quite different amounts of data available. Thus a significant spread in the extent of the analysis is inevitable. Work is likely to continue in all the countries, extending the breadth and depth of the analysis. Part of this continuing work will make up Phase Three, which takes the methodological approach a step further by concentrating on such issues in two countries: Venezuela and Zimbabwe. The Phase Three studies, initiated in October 1993, are financed by UNEP and are scheduled for completion in mid-1994.

Publications in 1993: 25,26 and 38

KIRSTEN HALSNÆS

ENVIRONMENTAL IMPACTS OF FUEL CYCLES IN DEVELOPING COUNTRIES

The Environmental Database (EDB) was developed for UNEP by the Stockholm Environment Institute's Boston Centre (SEI-B) and is jointly supported by the Centre and SEI-B as part of UNEP's effort to encourage greater incorporation of environmental issues in energy planning in developing countries. The interactive database contains extensive quantitative information on the environmental loadings associated with a wide range of energy production and consumption technologies. EDB can be used on its own to store and provide individual environmental loading coefficients, or in conjunction with an energy model, such as SEI-B's computerized energy planning software, Long-range Energy Alternatives Planning (LEAP). In this way the environmental loadings of specific energy scenarios can be compared. The LEAP/EDB system is now installed in over 30 countries and is being actively used in numerous energy-environment studies.

Part of the Centre's work with EDB over the past year involved extending the coverage of the database by incorporating specific emission data from the CORINAIR European emissions inventory. The database now contains a comprehensive selection of data for environmental loadings associated with European technologies, as well as the US and developing country data already entered. The Centre has also distributed copies of EDB to a number of users in developing countries, and supported participating countries in the GHG Abatement Costing Study in the use of LEAP/EDB.

The main effort associated with LEAP/EDB during 1993 was the initiation of a new UNEP-financed collaborative project on fuel cycle analysis. The project is being carried out in collaboration with SEI-B and is aimed at enhancing the LEAP/EDB system to perform fuel cycle analyses and test this capability in a number of case studies. This involves identifying key issues relevant to full fuel cycle analysis in developing countries and developing appropriate analytical methods to include these considerations in making energy policy decisions.

Environmental analyses of energy use often identify and focus exclusively on the air pollutant emissions (e.g. SO_X, NO_X, CO_2) associated with fuel conversion and combustion. However, these are only two of many stages in the "fuel cycle" (see box). Significant environmental impacts can also be associated with energy resource exploration, extraction, facility construction, transportation, distribution, storage, waste disposal and facility decommissioning. Similarly, the impacts of hydroelectric development and biomass resource use, which are highly site-specific and difficult to quantify, are often under-emphasized.The UNEP/SEI-B Fuel Cycle Analysis project focuses on the identification and quantification of potential fuel cycle impacts that might otherwise be overlooked.

The project concentrates on direct on-site impact and loadings. These loadings comprise the air and water emissions, waste generation, and local land-use and ecosystem impacts associated with the provision of a particular final fuel, including the loadings and impacts from all major stages required to deliver the fuel to its final user. This level of analysis does not indicate the final damage that might result from the energy activity. Damage estimation requires modelling the transport, exposure, and response relationships that govern the fate and final impact of initial loadings. Analysing such relationships is beyond the scope of the current project.

Three case studies are planned,

Some elements of the fuel cycle for gasoline-powered transport

Activity	*Possible Environmental Concern*
Locate oil deposit	*(road building in pristine areas)*
Drill oil well	*(construction, land use, accidents, solid waste)*
Extract crude oil	*(spills, gas flaring)*
Transport crude oil to refinery	*(accidents, spills)*
Refine oil into gasoline	*(air emissions, solid and hazardous wastes)*
Transport gasoline to filling station	*(accidents, spills)*
Fill cars with fuel	*(leakage from storage, evaporative emissions)*
Operate vehicle	*(evaporative and combustion emissions)*

spanning the three developing continents Latin America, Africa and Asia, and highlighting different fuel cycle alternatives. Primary considerations in choosing specific countries are the extent to which LEAP/EDB is already being used, the existence of parallel ongoing activities, involving either the UNEP Centre or SEI-B, regional coverage and representative fuel cycles. The countries selected for the studies so far are Sri Lanka and Venezuela. Work has already been initiated in these two countries in 1993 through missions by Centre and SEI-B staff. A third case study in an African country is under consideration.

The three developing country case studies form an important part of the project since these supply specific data on relevant fuel cycles, provide a test bed for the new methodology and allow the tool to be geared to the needs of developing country planners and issues.

Completion of the project is planned for the end of 1994. In addition to the output in the form of an enhanced LEAP/EDB tool for fuel cycle analysis and associated documentation, the activity will be the subject of a synthesis and review workshop planned to take place in the latter part of 1994. Here case study participants and other LEAP/EDB users will be brought together to assess the applicability of the analytical approach and develop priority areas for further research.

Publications in 1993: 39

Gordon A. Mackenzie

Implementation Strategies in Integrated Resource Planning

In Phase II of the UNEP Greenhouse Gas Abatement Costing Studies, it was found that most developing countries could identify measures that could reduce emissions of greenhouse gases as well as local pollutants, with modest increases or even decreases in energy system cost (i.e., negative net cost).

Any national strategy would, however, have to consider broader national costs and benefits, as well as long-term social and economic effects of each option on the relevant actors. It may also be necessary for the country to consider its institutional capacity to implement a set of options even if funding were available.

New programme area for the Centre

The Centre has in this context decided to initiate a set of new projects to gain experience and develop practical examples of the development of implementation strategies for environmentally sound energy options.

Experience from the on-going national studies and the GHG abatement analysis shows that recognition must be given to the barriers to adopting efficient end-use technologies and environmentally benign supply technologies, in order to design practical policy strategies to overcome these barriers. Experience shows that though efficient technologies already exist that could reduce energy use by 20-50 percent, it is not enough just to assume that available technology can be translated directly into actual energy savings, nor to assume that the costs of implementing policy instruments to overcome the various barriers will be negligible.

The implementation assessment needs to be country or sub-country specific because the implementation issues involved for specific technologies and strategies will vary from one country to another according to different social structures, regulatory systems, institutional capabilities and broader cultural factors.

Three new activities have been established with institutions in Maharashtra (a major state in India), Sri Lanka and Zimbabwe. These activities will enhance the understanding among local policy planners and researchers of implementation strategies to reduce environmental impacts of energy usage and related institutional issues.

The final product will be plans that can be applied in Maharashtra, Sri Lanka and Zimbabwe, employing domestic resources and attracting international funding.

Strategic Options for the State of Maharashtra

The objective of the project is to identify promising Environmentally Sound Energy Technologies (ESETs) for various energy related activities and make a detailed assessment of the implementation costs associated with their adoption at the operational level in India. The methodology developed will be applicable to other states in India and in other developing countries.

The project is undertaken in collaboration with the Indira Gandhi Institute of Development Research (IGIDR) located in Bombay.

In the project some selected supply-side and demand-side energy related activities will be studied. The supply side activities included are:

a) thermal power station efficiency particularly auxiliary losses,

b) transmission and distribution losses in Maharashtra State Electricity Board's (MSEB, a major state-owned utility in the State) system.

The demand-side study will cover options for the high-tension industrial sector in Maharashtra.

ESETs for these activities will be analyzed. The project was initiated in November 1993 and will be completed in June 1994. Centre staff visited IGIDR early November to initiate the first activities, and Dr. Painuly from IGIDR worked at the Centre all of December.

The State Secretary for Energy has welcomed the initiative and the Chairman of MSEB has instructed his staff to work with IGIDR. Both policy makers have emphasized the need for an action plan that should be as realistic as possible, to start implementation as soon as results are ready.

Implementation Strategy for Zimbabwe

This project was started at the end of 1993 with a study of various energy-related activities in Zimbabwe and their estimated contribution to environmental impacts, focusing on atmospheric emissions. Electricity generation and use, coal mining, and industrial usage of energy will be studied.

The activity will result by mid-1994 in the preparation of an Action Plan for reduction of atmospheric and local pollution caused by energy-related activities over the next ten years. The project focuses on 'no-regrets' (negative net cost) options or low-cost measures.

The activities will focus on options in power production and use, agriculture, coal mining and manufacturing industry and work closely with key institutions in these subsectors.

The project builds directly on the existing collaboration in the GHG abatement project where Zimbabwe has been participating since the beginning. It will be implemented jointly by the Centre and the Southern Centre for Energy and Environment with the former playing the lead role in design, planning, monitoring and reviewing of project activities, with the latter carrying out the country level activities in consultation with the Ministry of Transport and Energy.

Integrated Electric Resource Planning in Sri Lanka

The purpose of this project is to develop and apply a practical approach to the design and implementation of Integrated Resource Planning (IRP) in developing countries through a collaboration with the Ceylon Electricity Board (CEB) of Sri Lanka.

The complex nature of modern electricity planning, which must satisfy multiple economic and environmental objectives, requires the application of a planning process that integrates these objectives and considers the widest possible range of traditional and alternative energy resources. IRP is the combined development of electricity supplies and demand-side management (DSM) to provide energy services at minimum cost, including social and environmental costs.

By assisting the CEB in the design of an IRP process, the Centre aims at demonstrating useful methods to integrate energy efficiency options and environmental aspects into electricity planning. The CEB has developed its first strategic plan, emphasizing three areas: rural electrification, private power generation and IRP.

While the major part of the project will be in 1994, the background analysis and the project planning and design has been prepared in 1993, including an initial visit to Sri Lanka.

The project will cover three general activity areas: *1)* assist the CEB in identifying the information needs of an IRP process, and in the development of an IRP methodology. *2)* collect information for the IRP process, especially in regard to energy-efficiency improvements, from both within Sri Lanka and international sources, this will be done by the CEB with assistance from the Centre. *3)* apply the LEAP/EDB analysis framework to quantify the environmental impacts of alternative electricity supply options, including the full fuel-cycle effects of biomass and fossil fuel-fired generation.

Joel Swisher and Pramod Deo

Risk
Analysis
Group

Risk Management and Chemical Accidents

An accident may place extra demands on gathering knowledge and supplying resources, when dangerous substances are involved. Increased attention has been directed towards chemical accidents ever since the Seveso accident in Italy 1976, which initiated a revolution in risk management and regulation of the chemical industry.

Risk management viewed as the integral activity of managing all sorts of risk at a facility covers both the industrial hardware and the industry's "software", i.e. operators, managers, operation plans and maintenance schemes. In the years since Seveso, the scope of risk management has gradually moved from process equipment towards human resources and higher level planning items. An important next step yet to be taken is viewing both the management of operational risks and chemical emergencies through the same pair of glasses instead of treating them as disconnected entities with their own rules, standards and specialists.

In 1993 the Risk Analysis Group conducted a study for JRC-Ispra of "Lessons Learnt from Emergencies after Accidents in Denmark Involving Dangerous Substances". The study is a contribution to a series of *Lessons Learnt* studies in EC countries. The concentration and size of chemical industrial plants in Denmark are small, measured on an European scale, but due to national variations in emergency organizations and in industrial management culture, Danish experience with chemical emergencies may still be of some interest. The work was done in close collaboration with representatives from the National Agency of Environmental Protection, the Danish Working Environment Service, the Commissioner of Police and the Emergency Management Agency. The period covered was 1980-1992 with seven cases selected:

- Dansk Sojakagefabrik, explosion, 1980
- Mustard gas bombs in fishing trawl, Baltic Sea, 1984
- Nordisk Alkali Biokemi, decomposition of pesticide, 1985
- Valdemar Larsen metal working, release of chlorine, 1985
- Matas warehouse fire, Aarhus, 1988
- Maribo seeds company, fire involving toxic substances and dust, 1989
- Næstved railway accident, release of acrylonitrile, 1992.

To facilitate making comparisons and extracting specific features, a data collection form was developed, based on the reporting used in the common EU database MARS at JRC-Ispra, with greater emphasis put on emergency measures and minor emphasis on the causes of accidents. Input to the study has included material collected for the MARS recording (three cases had already been reported there), and articles in newspapers and periodicals. The material was supplemented with material procured by the representatives and with informations from interviews with key persons involved in the actual cases.

Some of the *lessons* shall be mentioned shortly: the chemical challenge to the hospitals' acute response units, attacks on breathing apparatus, need for more technical education of firemen, the special dangers from subsea storages of chemical weapons. Doctors and health specialists operate in a quite different world than firemen and police, and the two cultures do not respond in a coordinated way to the introduction of new chemicals, new technologies in the industry etc. This means that during a specific accident, synchronization losses and delays may occur, because two different networks are set in motion in order to find proper treatment methods and administer antidotes. Emergency units focus on one or a few accidents at a time, while hospitals are involved in several other tasks at the same time.

Exposure to aggressive chemicals may cause delayed destruction or deterioration of components in breathing apparatus. This equipment is checked immediately after use on a regular basis, but such inspection may not trace chemical activity with delayed effects.

The chemical and technical knowledge of firemen varies considerably, and one of the remedies is the development in many countries of chemical databanks to make the needed information available on most of the chemicals met in accidents. The question raised with the study is whether the background knowledge of the typical firemen is developed sufficiently to cope with the data in the databanks.

World war II left Danish sea areas with regions where mustard gas bombs had been "buried", and during the last twenty years with the application of more intensive fishing methods and deeper-going trawls, these bombs are sometimes caught in a trawl, giving rise to rather particular hazards. There are uncertainties about locations and amounts of these weapon storages in the sea, and it is difficult to keep the crews of all fishing boats informed and properly instructed. Nevertheless, there have been only rather few injuries, but the handling of some cases has been troublesome. Corrosion has developed to various extents, requiring delicate handling, and the cleanup after mustard gas spreads on boats, fishing gear and equipment is rather difficult.

The mustard gas bomb threat shares many parameters with the generic difficulties of the typical transport accident: the dangerous substance is unattended, the injured persons belong to a large and not very specific group, there may be a large distance to both data, key experts and particular mitigation means.

Integration has been seen in the administration and organization of emergency forces, with the American Federal Emergency Management Agency, the Swedish Räddningsvärket and the Danish Beredskabsstyrelsen and probably several others. Integration is central to sensible risk management, and integration is a basic element of any data banking system. But integration must also assimilate geographical, organizational and cultural distances and borders under actual performances, therefore most accidents involve organization, communication and data handling as the primary and perhaps most critical steps.

Also, in society's risk regulation many decisions are simple compared to the task of establishing integral risk management in a geographic or municipal region or a town etc. including regulation of industrial risk, traffic risk, schools, entertainment, airports and so on. In 1993 a EUREKA initiative was launched with the aim of developing a methodology for regional risk management. The method focuses on preventing accidents and establishing databases and analysis procedures for review of accidents and incidents to continually improve risk management plans. The users of the methodology are local / governmental authorities and safety services like rescue service and fire brigade.

Carsten D. Grønberg

Reliability Assessment Combining Stochastic and Deterministic Phenomena

As part of the work under the CEC's TELEMAN research programme a reliability analysis combining stochastic and deterministic phenomena has been performed. Normally the system reliability is calculated from component reliability data which are specified by probabilistic measures. In this case it has been necessary also to consider the influence of γ-radiation on the performance of the components, and this influence turns out to be of a deterministic rather than stochastic nature.

The TELEMAN research programme has the objective to develop advanced teleoperators (robots) that can operate in hazardous or disordered nuclear environments. As part of the programme's ENTOREL and INGRID projects, the Risk Analysis Group performs reliability analyses, taking into consideration the hostile environments with high levels of γ-radiation as the dominant factor. Although the machines constructed in TELEMAN are not actually going to operate in a radiation environment it must be demonstrated that they would be able to do so - maybe with some modifications, replacing (cheap) non-radiation-tolerant components with (expensive) radiation-tolerant ones. Depending on the potential use of the machines the expected radiation doses vary from almost nothing to the order of 10^6 Gy of γ-radiation.

The effects of ionizing radiation on components and materials

Relevant components and materials which are susceptible to radiation damage are, for example: electronics, sensors, fibre optics, insulating materials and lubricants. The usual effect of the γ-radiation is a gradual change in properties rather than a sudden break-down. The gain of bipolar transistors, for example, normally will decrease with increasing dose, optical fibres will darken and lubricants will become stiff. For quite a large number of components and materials measurements have been performed to establish the change in properties as a function of dose. This means that, in principle, a function or a table can be set up giving the degree of degradation at any given dose, i.e. the degradation process is deterministic.

Radiation also affects the "traditional" reliability of the components in the sense that the degradation of materials will increase the probability of failure of a component in the same way as increased temperature, moisture etc. will do. This kind of effect can be taken care of either by multiplying the failure probability by a factor for each mechanism, the so-called π-factors, or by means of proportional hazards modelling.

The system considered

In the INGRID project the purpose is to build a research machine of the gantry type for heavy-duty operations, typically in reprocessing plants. Figure 1 shows a sketch of the system; the robot is mounted on a telescopic mast which in turn is mounted on the transverse carriage of the gantry system. The robot is a NEATER robot, manufactured by AEA Technology on the basis of a commercial PUMA robot produced by Stäubli Unimation. NEATER is designed to tolerate radiation doses up to 10^6 Gy. The robot is being equipped with a number of special tools, cameras and sensors in order to test the system in a number of scenarios. The scenarios will comprise tasks such as decontamination, cutting and welding performed on simulated highly radioactive equipment. In the case studied the dominant radiation source will be a (mock up) calciner intended for forging highly radioactive waste into glass cylinders for final disposal. The radiation dose rate from similar "real life" equipment could go as high as 1500 Gy/h. Since a main part of the objective of INGRID is to demonstrate advanced control systems and some degree of "intelligence" and autonomy in the system, there will be a need for some electronic equipment in the highly radioactive environment.

Reliability modelling

There are three major inputs to setting up a reliability model: the design of the machine, the tasks which the machine is to perform, and the types of undesired failure ("top events") which are to be examined.

Based on the scenario specifications laid down in the project, a list of "elementary tasks", such as "Change tool" and "Robot motion", was set up. The elementary tasks, combined with information

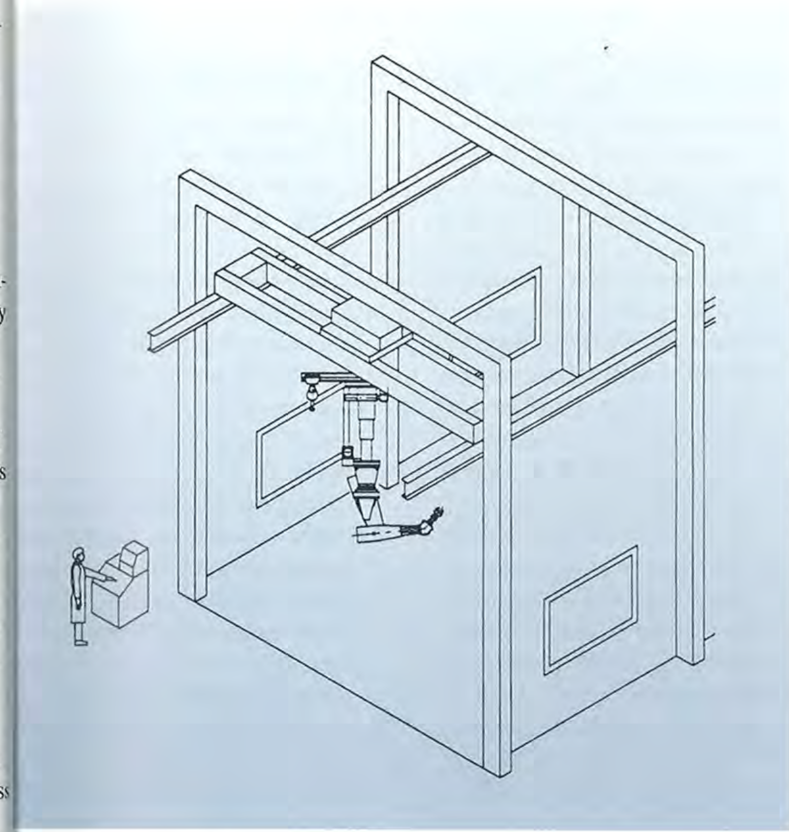


Figure 1. Sketch of the INGRID gantry system

on which tools and sensors (and a few other additional features) are used, define the tasks to be performed in the various scenarios. The next step was to set up a table, showing for each task the equipment needed to perform it. This list forms the foundation for the assessment of consequences of component failures to scenario execution.

The reliability model itself is a compilation of failure possibilities for all components of the machine plus possible human errors, and the consequences of these failures, alone or in combination, on the ability of the machine to perform its tasks. The model enables the user to study various types of "top events", from the relatively innocent "Nut runner failure" to the fatal "Loss of robot (in a high-radiation area)". The reliability model was established by means of a set of computer programs which can be used to sort out the "cut sets", i.e. the combinations of component failures leading to a given top event. In addition, the program system can perform quantitative analyses, calculating the probabilities of the top events, provided that reliability data exist for the basic events.

Modelling of radiation damage to the system

The reliability model described above can, furthermore, be used to produce a ranking of the cut sets – and thereby the equipment – with respect to radiation damage. This can be done by using *radiation degradation factors* for the components as input instead of the basic event probabilities which are normally the input in reliability calculations. The radiation degradation factors, Δ, are defined as

$$\Delta = (P_0 - P_t)/(P_0 - P_f),$$

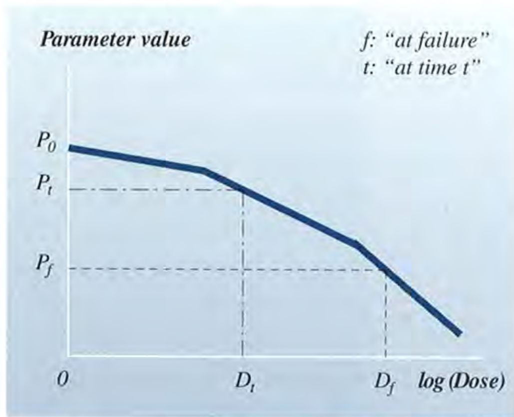
where P_0 is the value before exposure of a characteristic parameter (e.g. the modulus of elasticity of a polymer), P_t the value after a total radiation dose D_t and P_f the value at failure.

Similar to the basic event probabilities, Δ will lie in the interval [0;1].

The parameter values were estimated for the relevant components and subsystems from *radiation degradation functions*. These functions, in turn, were specified on the basis of documentation available from the INGRID partners, the ENTOREL project and open literature. This was done for all the basic events in the cut sets relevant for the scenario studied. The degradation functions used so far were piecewise linear functions with logarithmic dose values and linear parameter values (see Figure 2).

The radiation dose D_t accumulated by a given component at time t is estimated by means of a small

Figure 2. Piecewise linear radiation degradation function.



Risø-R-724(EN)

number of *radiation zones* (6 at the moment). The various parts of the robot are grouped together in zones; typically the end effector is in one zone (the most "hot" one), the robot forearm and the equipment attached to it are in another, and so forth. A particular zone is the "white" zone without radiation; most control equipment will be in this zone. In each zone the dose is assumed to be the same all over and equal to the dose to the centerpoint of the zone. The dose is established by estimating the duration of time that the centerpoint of the zone operates in a given dose rate and multiplying time and dose rate. The dose rate is calculated by means of radiation shielding codes when the source strength is known.

In the preliminary calculations the value of the exposure time used was 2000 hours, corresponding to the service intervals prescribed in the TELEMAN programme. The calculations, which were performed with values of the maximum dose possible, resulted in a ranking of the components involved in a given top event with respect to their Δ-value. The results showed that few components would survive the radiation environment for the 2000 hours. It must be stressed, however, that these results are very preliminary and that several assumptions and submodels need to be verified. What the calculations do indicate is that the procedure chosen is suitable for identifying weaknesses in the design and materials choice and possible needs for radiation hardening of components and materials.

Publications in 1993: 35

Kurt Lauridsen,
Hans E. Kongsø and
Palle Christensen

Toxic Hazards from Chemical Warehouse Fires

In many countries there are a large number of chemical plants and warehouses that handle and store substantial amounts of hazardous substances, such as pesticides. Chemical fires seem to be one of the most important hazards from these activities.

Over the years a number of fires have actually occurred at some of these chemical installations. Large quantities of chemicals have been involved with the formation of significant amounts of toxic fire effluents. These products can be dispersed with the fire plume causing harm to humans and the environment.

Today only limited documentation is available concerning assessments of the potential consequences from fires at chemical plants and warehouses. This limitation arises from a general lack of knowledge of the chemical nature and amounts of the toxic fire effluents that can be generated. The work described below was initiated in order to remedy some of the problems.

Source Term Characterization

The research project entitled "Combustion of Chemical Substances and the Impact on the Environment of the Fire Products" is currently being carried out. The project, which is sponsored by the CEC STEP programme, was initiated in 1991 and will be completed in July 1994.

The objective of the project is to obtain the first data concerning identification and quantification of the fire products from fires in warehouses containing commercial chemicals. The project comprises experiments of various scale (micro-, small-, medium- and large-scale) in order to identify the source-term characteristics and the relation between bench-scale testing and real fires. The results of the project will be used in future risk assessments of chemical plants.

The participants in the project are: Risø National Laboratory which acts as coordinator, South Bank University (U.K.), VTT – The Technical Research Centre of Finland (Finland), SP – Swedish National Testing and Research Institute (Sweden), and Lund University (Sweden).

Results of the Micro-scale Experiments

Risø has been responsible for the micro-scale experiments which were completed in 1993. They were carried out using a furnace in accordance with the DIN 53 436 standard and the combustion products generated were analyzed. On-line measurements of O_2, CO, CO_2, NO_X and SO_2 were carried out, HCl, HCN and NH_3 were absorbed in various solvents for later determination of the total production, and the organic compounds produced were trapped in impinger bottles cooled to -80°C and identified by GC/MS.

Different types of compounds were tested including three organophosphorous insecticides, a chlorphenoxy herbicide, a heavily chlorinated insecticide, a chlorinated solvent, a fertilizer and four polymers. Various experimental conditions were applied in order to approach simulation of different fire scenarios. Even though a number of results from experiments with the polymers in the DIN furnace are available these substances were tested in order to be certain that the DIN results could be reproduced. The results from combustion experiments with the polymers should also be used in the scaling study, since this substance type is the only one that could be tested on a large-scale.

In general it was observed that the amounts of CO_2 and CO produced increase and, accordingly, the concentration of O_2 decreases with rising temperature. The chlorinated compounds produce rather high concentrations of CO compared with the non-chlorinated (especially if the substance is heavily chlorinated), i.e. the CO_2/CO ratios are rather low for the chlorinated compounds. The combustion of chlorinated compounds generates high concentrations of HCl as well. The production of HCl increases with rising temperature.

It was also concluded that organic thiophosphate pesticides generate very high concentrations of SO_2. In many cases an almost quantitative conversion of the sulphur atoms in the compound to SO_2 is seen. Rather low concentrations of NO_X and very low concentrations of HCN have been observed both from nylon and from the nitrogen-containing organophosphorous pesticides.

Furthermore, nearly all the compounds tested produce a large number of different organic combustion products, especially at low temperatures. However, rather few organic products were observed from the organophosphorous pesticides and chlorobenzene, especially at high temperatures.

Finally, the toxicity of the combustion atmospheres has been evaluated by means of an N-gas model. It can be concluded that pesticides generate highly toxic products by combustion. The concentrations of HCN and NO_X from nitrogen-containing compounds are not very high but because of their toxicity these products are still important. The production of HCl from the chlorinated compounds is very high, and so is also the production of SO_2 from sulphur-containing compounds.

Evaluation of Scaling Effects

The first preliminary evaluation of the scaling effects has been carried out. Expanded polystyrene and Nylon 66 pellets have been chosen as model compounds and combusted in micro-scale (DIN 53 436), cone calorimeter (normal and reduced ventilation), medium-scale and large-scale tests. The combustion products and fire behaviour have been studied as a basis for the evaluation. The results indicate that it is possible to relate results from different scales. The micro-scale, cone calorimeter and medium-scale experiments can be used for evaluating the worst case situation with respect to CO production in the case of a chemical warehouse fire. In all scales the production of HCN and NO_X from Nylon 66 was found to be rather low, but these highly toxic fire effluents might contribute significantly to the toxicity of the fire plume. Finally, the organic combustion products might also contribute to the toxicity.

Development of Guidelines for Management of Chemical Fires

Other problems which remain to be solved concern chemical warehouse fire prevention and mitigation. In order to study these subjects a project entitled "TOXFIRE–Guidelines for Management of

Foto: Boye Koch

Fires in Chemical Warehouses" was initiated in October 1993. The project will run for three years. The project is sponsored by the CEC ENVIRONMENT programme. The participants in the project are identical with those in the STEP/ Combustion project supplemented with DMU – The Danish National Environmental Research Institute and FOA – The Swedish National Defence Research Establishment. Risø is the project coordinator.

The objective of the project is to develop the basis for two sets of guidelines in relation to fires in chemical warehouses; guidelines for the safety engineers to be used in accident prevention, and guidelines for the fire brigade to be used if an accident nevertheless should occur. The guidelines will be the outcome of a detailed and systematic study of chemical fires supplemented by experiments based on model compounds to determine important properties of the substances involved, the source characteristics and assessment of parameters of importance for fire scenarios. Also the consequences to humans and the environment of the chemical fires will be included.

Screening of Substances for Classification and Source Characterization

In the TOXFIRE project Risø will take care of the initial screening of substances. This will be done by carrying out a large number of pyrolysis experiments in an inert atmosphere followed by GC/MS. Even though such pyrolysis experiments are very different from "real fires" the studies give some information about the types and amounts of products from thermal decomposition. Some of these products are expected to survive a flame and will therefore be important especially in a fire under oxygen-deficient conditions. The compounds for the screening experiments will be chosen mainly from the group of substances covered by the EEC directive 82/501/EEC on "Major Accident Hazards of Certain Industrial Activities", but other compounds which are stored in large amounts will also be included.

Some preliminary pyrolysis experiments with the pesticides investigated in the STEP/Combustion project have been carried out in 1993 in order to compare results from the pyrolysis/GC/MS method with those obtained earlier with the DIN furnace. The first results indicate that a greater variety of different compounds are observed in the pyrolysis experiments compared to the DIN furnace tests.

Based on the results of the screening some selected substances which are expected to represent characteristic groups will be subjected to micro-scale combustion experiments using the DIN 53 436 method. In order to be able to quantify (on-line) a larger number of combustion gases an FTIR instrument has been bought. The use of such an instrument could also be time-saving and produce more reliable results. In 1993 the initial testing of the instrument was carried out based on a few combustion experiments. These tests indicate that the instrument is able to fulfill the requirements.

Publications in 1993: 34, 67 and 68

LENE SMITH-HANSEN

EXPERIMENTS W ARGE NATURAL GAS FLAMES

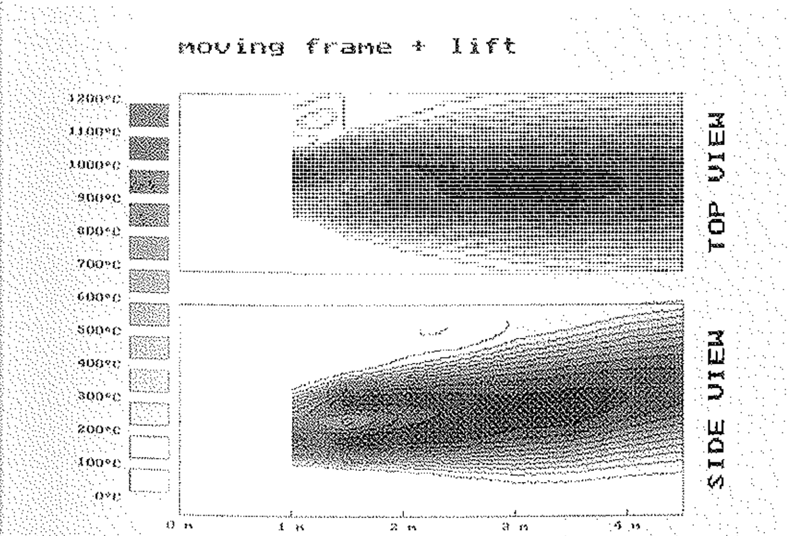
Flammable gases such as propane or natural gas are kept under pressure when stored and handled. A leak from a broken pipe will, if ignited, give rise to a jet flame which can endanger other parts of the equipment and cause a severe fire escalation. Thus even a relatively small jet fire can be the event triggering a major accident. For this reason jet flames are worth studying.

Risø has a test field where natural gas flames can be studied. The flames produced are up to 10 meters long with a power of about 5 MW. The work is part of a collaboration between a number of European institutions making large scale experiments, wind tunnel simulations and theoretical models. The results are used to validate flame models, which can be used to estimate the consequences of accidents.

The modelling of real accidents, such as the escalation of a jet fire, is complicated and involves a complex of different phenomena described by a number of submodels. The kind of experiments performed at Risø are not meant to be direct simulations of accidents. Instead idealised situations are studied, which highlight isolated aspects of the chain of events of a real accident. In most experiments the free flame in itself is investigated, but heat transfer to simple objects such as plates and cylinders impinged upon by the flame has also been measured. Using a simple experimental set-up makes it easier to interpret the result and to pinpoint possible deficiencies of submodels. Experiments simulating complex accidents test the result of combining many submodels. This is equally important, and such work goes on in other European countries.

Figure 1 is an example of data delivered to modellers. It shows the temperature distribution in a horizontal flame pointing downwind. In order to produce the plot the raw data from measurements of temperatures taken at a large number (512) of positions in the flame were analysed using a technique developed by Risø, which removes the random motions of the flame caused by large scale atmospheric turbulence. From the data analysis of the measurements it is concluded that the random

Figure 1. Analysed flame temperature distribution. The figure is a dump from a PC screen.



motion, sometimes referred to as meandering, is well correlated with measurements of the upwind atmospheric turbulence, and that the random motion can be reconstructed from the readings of a cup anemometer and a wind vane located close to the flame. For modellers this is an important observation, since it reduces the meandering to a meteorological effect, which can be separated from the internal dynamics of the flame. It should be noted that flame meandering greatly affects the way heat is transferred to objects in the flame.

Unlike flames fuelled by higher hydrocarbons (and candle light flames), the natural gas flame generates very few soot particles. The flame is therefore not bright yellow as flames usually are, but almost completely transparent and, in fact, barely visible. For this reason an infrared video camera was used to make pictures of the flame. Figure 2 shows an example of an analysed image obtained by means of an infrared video. It is based on a large number of digitized images, from which the meandering was removed using a procedure similar to the one applied to the temperature data. The image represents the shape of a flame which is not disturbed by the random eddies of the atmosphere, which is the shape theories predict. Analysed images were used to deduce simple geometric characteristics (e.g. length and width), in order estimate the influence of the mean wind speed, the nozzle diameter and the gas exit velocity on the flame shape. The information obtained in this way is less detailed than the temperature data, but advantage of this technique, compared to the direct measurements of temperatures, is that the experiments are much easier to perform, so that a larger number of experiments can be done.

The length of the flame is of particular importance for risk estimates. For a given fuel injection rate the flame length was found to be nearly independent of both the wind speed and the nozzle diameter (for a fixed fuel rate the nozzle diameter determines the gas exit velocity). A dependence on the wind speed had been expected, but none was detected. Dimensional analysis suggests Froude scaling, which means that the ratio of the flame length to the nozzle diameter, L/D, is a function of two dimensionless numbers: the ratio U_a/U_e of the wind speed to the gas exit velocity and the socalled Froude number, Fr, which is equal to U_e^2/Dg (L = flame length, U_a = wind speed, U_e = gas exit velocity, D = nozzle diameter and g is the acceleration due to gravity). With no detectable influence of the wind speed (L determined solely by the fuel rate) the only possible relation consistent with the Froude scaling is that L/D is proportional to $Fr^{1/5}$. Figure 3 shows the results plotted as L/D versus Froude number. In this log-log plot $Fr^{1/5}$ is a straight line with slope equal to

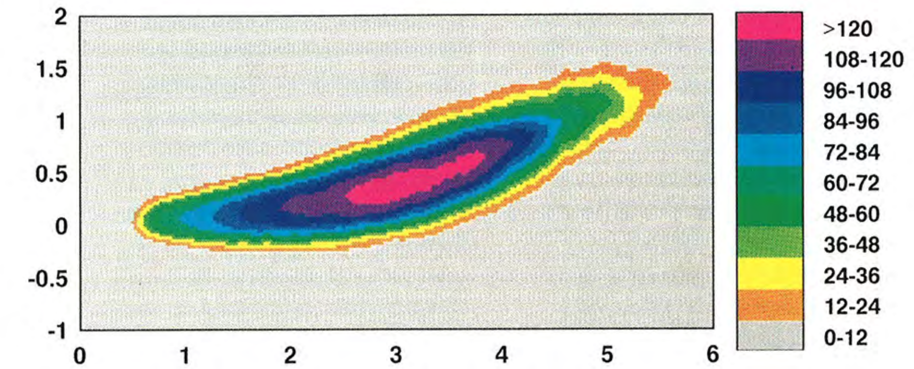


Figure 2. Example of an analysed infrared video image.

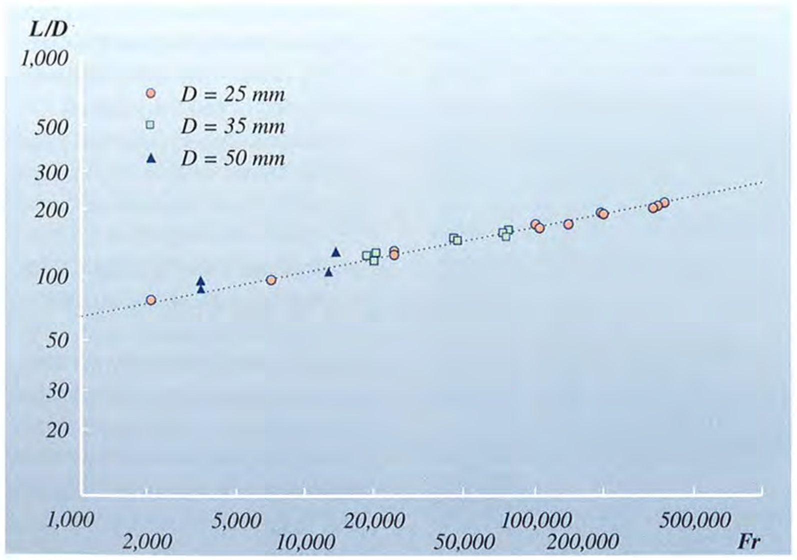
1/5 as indicated by the dotted line. It is evident, that our results support the Froude scaling. At the same time flame model calculations support the result that L/D is proportional to $Fr^{1/5}$. The conclusion is therefore that theory and experiments agree, and that Froude scaling seems to work.

The results also raise a question: what happens if we vary g? Technically this can be done by performing experiments in an accelerated system (e.g. an elevator or an aeroplane). According to the relation deduced from the experiments (in which g was constant), the flame length decreases if g is increased. This behaviour is peculiar: the harder the flame is 'pulled' by buoyancy forces, the shorter it gets. An experimental verification of this would be a crucial test of the idea of Froude scaling. Performing such an experiment was, however, was not part of this project, and has to be left for the future.

Publications in 1993: 44

SØREN OTT

Figure 3. L/D vs. Froude number (see text) deduced from the analysis of infrared images.



RELIABILITY OF THE SAFETY [SYSTE]MS OF WIND TURBINES

The photo illustrates what happened when the safety system of a wind turbine failed. Incidents like this one naturally raise the question of the safety of wind turbines, and attention is drawn to their safety systems, the failure of which is the cause of most of the incidents that have occurred.

For the purpose of developing a method for evaluating the failure modes and the reliability of the safety systems in wind turbines, a project was established under the Danish Energy research programme. It was carried out in a cooperation between BONUS Energy A/S, ELSAMPROJECT A/S and Risø, and completed in 1993. From Risø the Test Station for Wind Turbines and the Risk Analysis Group participated.

A proposal for the following method of analysis of the safety systems of wind turbines was put forward. The method is composed of selected parts of known techniques in an adapted form and consists of the following steps:

1. Specification of the event (top event) to be analysed
2. Cause-consequence analysis of the top event selected
3. Analysis of the event sequences leading to the top event
4. Failure mode and effects analysis of the systems involved
5. Fault-tree analysis corresponding to the top event
6. Calculation of the probability of occurrence of the top event

The proposed method af analysis was applied to a 150-kW Bonus wind turbine. The event analysed was a runaway incident. The cause-consequence diagram for this event is presented in figure 2. The resulting probability of occurrence of a runaway incident, based on the available data was 1/900 wind turbine years. This is probably a pessimistic result, since no such incident has actually occurred with this type of wind turbine during more than 900 turbine years.

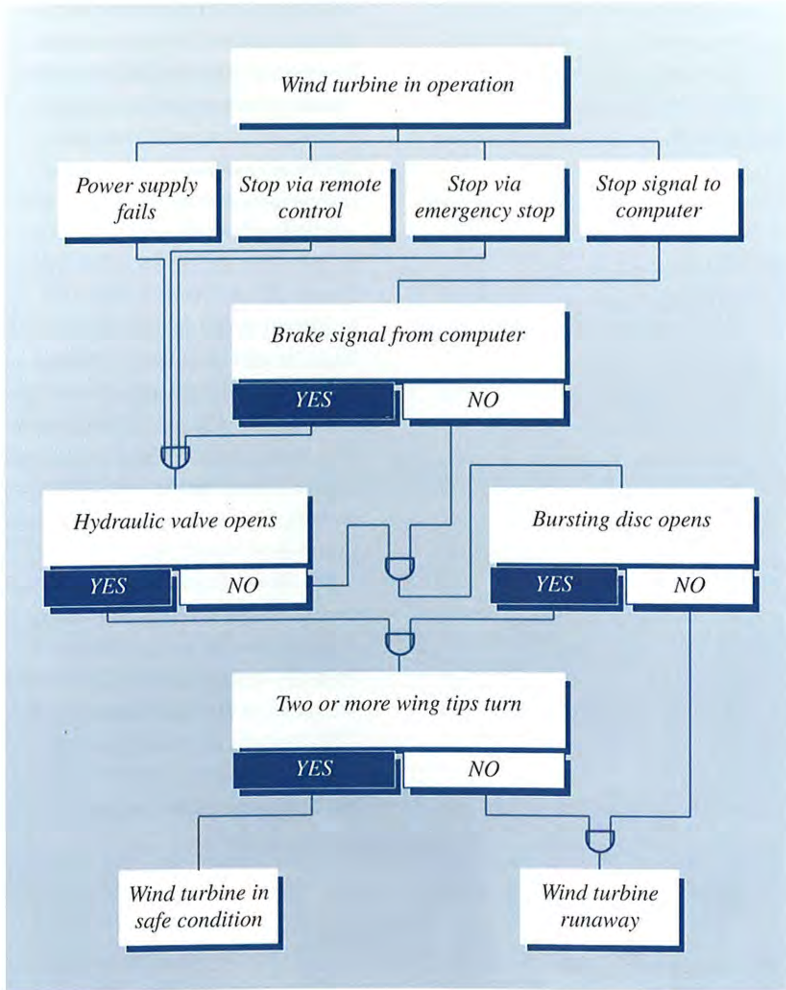
The proposed method of analysis was evaluated in relation to all runaway incidents from all manufacturers of a design similar to the one analysed. The conclusion was that to the best of our judgment the method of analysis-perhaps with a single exception- would in fact have been able to identify all of the incidents in advance. On the basis of the experience from the runaway incidents, the authorities should consider introducing the requirement that all wind turbines shall be adjusted to stop at the maximum wind speed at which the respective wind turbine type has been tested.

The work will be continued in 1994 and include the establishing of a practical method of analysis. The method shall be applicable for the manufacturers of wind turbines in the design work for evaluating the reliability of the safety systems in new and old types of wind turbines. The method shall also be applicable by the authorities for evaluating the safety of wind turbines. Further, the method shall be a tool for securing the feedback of operational experience in a systematic manner for the benefit of the design work.

A database shall be established on the basis of the existing work requisition systems and databases. Special efforts must be made to insure that the method has good possibilities of extensive application. It must have a suitable user interface and be easy to use. It shall contain data concerning component and system failures, and be applicable by the manufacturers and the authorities in their work on evaluating the reliability of the safety systems of wind turbines.

HANS ERIK KONGSØ

Runaway of a wind turbine.



Cause-consequense diagram for a runaway incident.

Cognitive Systems Group

Demonstration of a Framework for Cognitive Work Analysis

It is generally agreed that current information retrieval systems in university, public and school libraries present major problems for users. These difficulties are particularly perplexing today when information retrieval skills play a major role both in education and, increasingly, in society as a whole. One of the barriers against providing students with information retrieval skills is the lack of programs for casual and novice users; other barriers exist between research libraries, public libraries, school libraries and education in schools. The purpose of this project is to describe how a framework for cognitive work analysis developed at Risø can be used to design systems for indexing and storing information for later retrieval and thus contribute to improving education and the use of libraries in schools. This work encourages a more integrated and interrelated approach in a Nordic cooperation called the "The Nordic Book House System for Information Retrieval" between Risø, Stockholms Stadsbibliotek in Sweden, Åbo Stadsbibliotek in Finland, The Finnish Bibliographic Data Supply Center and the Peder Lykke School in Denmark. The cooperation was supported by the Council of Nordic Ministers.

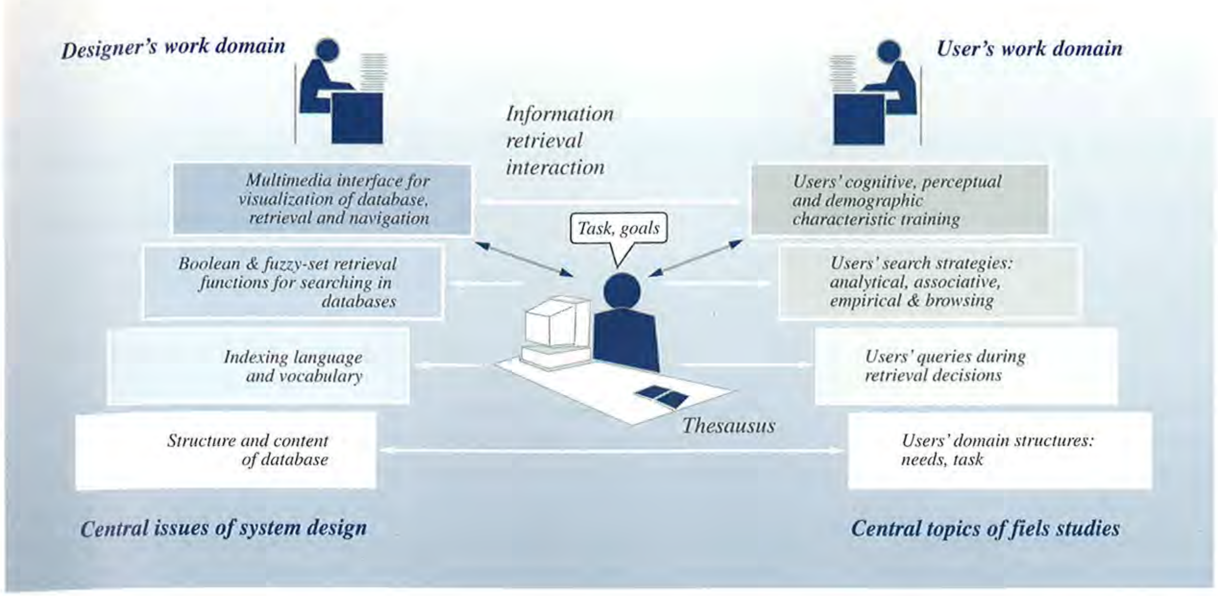
The Nordic work in 1993 included a survey of twenty-seven on-line information retrieval systems actually used in library institutions in the Nordic countries of Denmark, Sweden, Norway, Finland, Iceland, Greenland and the Faero Islands as well as a study of related research on user access to databases focusing on database content, system functionality and interfaces.

The main conclusions drawn were that the majority of today's commercial systems favour:

1. Database records consisting of mainly bibliographical information, short abstracts of content and a field for controlled content keywords. These few dimensions of information are insufficient in comparison with users' multidimensional needs. The vocabulary in bibliographic records is incompatible with the language brought to the system by the users. For both reasons users fail to match their own need formulation with the system's subject vocabulary.

2. A single search strategy and user-system dialogue which does not tailor the retrieval functionality to users' preferred interaction modes and multiple strategies. This leads to navigational confusion and frustration for the user during the search process.

3. Interfaces which are not transparent either with respect to showing database content or the functionality of the system and the commands needed to activate access to database information. This leads to a lack of understanding with respect to the use of the system facilities and partial use of the options provided by the system and missing opportunities to complete initiated searches.



The figure illustrates the transformations of the key topics of field studies into their representation in system design within the framework for cognitive work analysis.

The figure shows the dimensions of the cognitive framework to be used in design of a system for retrieval, indexing and database storage which circumvents these problems by analyzing *1.* the user's domain to enrich and structure the database information *2.* the task requirements to determine the specificity and exhaustively in the choice of indexing language and document representation *3.* the users' task strategies to determine navigational paths to the database content *4.* the knowledge and demographic characteristics of the target user population needed to develop comprehensive interface displays.

This approach was illustrated in developing the book House Write system which in the school library context was used to:

1. improve the education and training of pupils in storing and retrieving information through a uniform platform – i.e. a system common for both the teaching situation in the classroom and the retrieval situation in the library. Book House Write can be an important facility for linking language from text analysis and indexing to language used for database development and information retrieval.

2. increase users' own searches in libraries by developing a system which would enable pupils to do their own indexing and database development for later searches in libraries more effectively and in direct response to their daily information needs for preparing classwork and leisure activities. Work then takes on a practical goal and has an effect that is physically visible and useful for the whole class.

The basic idea is that pupils can progress gradually in their learning about the storage of information in the database, and that indexing can be made with very little effort and practically no prior knowledge about professional indexing principles. Two experiments were conducted to gain experience in the use of the system:

A school class in the sixth grade at the Peder Lykke School created their own database as a cross disciplinary project between the library and school teachers. The overall purpose of the experiment was to teach pupils how to prepare data for information retrieval through the selection of the keywords necessary to communicate the most important aspects of a book by means of a computer for subsequent database retrieval.

In a second Book House Write project for the ninth grade, students created a database with high quality books chosen by their teachers for retrieval in the school library. The purpose was to widen the pupils' reading perspectives by use of database retrieval.

Both experiments showed that using the Book House Write improved the pupils' understanding of database retrieval, and it motivated a change in their reading patterns.

The system was released in the summer of 1993 by Apple Computers A/S on a CD ROM and by Risø on discs, and has been distributed to Scandinavian schools and school libraries.

Publications in 1993: 45 and 46

Annelise Mark Pejtersen

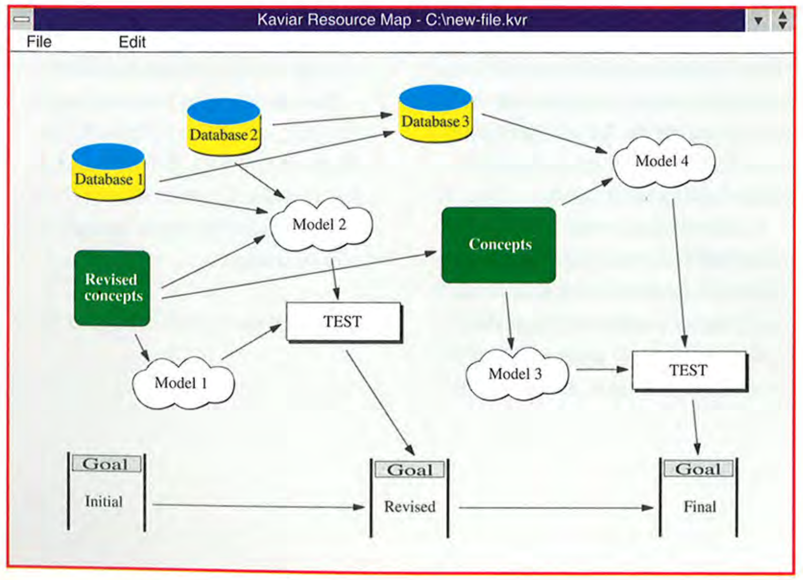
Information Technology in The Medical Domain

IT support in the medical domain draws increasing attention. The medical domain is characterised by high complexity, high risks, experts solving complex problems under time, ethical and economic constraints. The KAVAS project is a three-year CEC-financed project initiated in 1992, with CRI A/S, Denmark as the main contractor. In order to support the medical professional in his research and development of new medical procedures for treatment of patients, the KAVAS project has been started with 12 collaborating European partners. The objective of the KAVAS project is to develop a prototype tool named KAVIAR. This tool combines knowledge acquisition from medical research professionals with knowledge extraction from data bases and example cases with an integrated quality assurance mechanism. The KAVIAR prototype will contain 5 modules. These are: the Knowledge Capturer (KC), The Machine Learner(ML), the Conditioner, the Quality Assessor and the User Computer Interaction(UCI).

During 1993 a general framework for the user-computer-interaction has been specified. The different phases of a medical research process are described from an empirical as well as a theoretical point of view. The different viewpoints lead to the same results:

The system must be *task oriented* in order to support the medical researcher in his work. There must be possibilities for the user to have *access* to and be able to *manipulate* data and knowledge. The two major model building tools ML and KC must be able to *support* each other. The user must have mechanisms for *keeping track* of the changes in the goals as well as in the status of a project.

This figure shows the different tasks the user has performed and can be used as an overview of the process the user has gone through to reached his/her goal. Functionality is derived from the UCI-framework.



From the analysis of what has been carried out so far, it is clear that (not surprisingly) medical researchers work in many ways like researchers in other domains. Data and knowledge are collected, tested, evaluated and manipulated in order to get a deeper and more coherent understanding of the problem at hand. The process is extremely iterative and often continues over a long period simultaneously with several other projects. We have identified a number of steps in which the research process proceeds. In reality they overlap and are iteratively intertwined. Some of the steps given below might not even exist in specific cases.

- Problem initiation
- Knowledge gathering
- Data and/or model gathering
- Familiarisation with the data and/or models
- Hypothesis formulation
- Evaluation and validation
- Publication and/or implementation

In the different phases of the research process different tools must be available to support the researcher in his work. Research is not a sequential process, but should rather be seen as an incremental one, where the researcher occasionally goes back to earlier work to explore or refine the results obtained so far. The UCI-framework discusses the different tools necessary to support the medical researcher in this explorative process.

Publications in 1993: XXXX

Steen Weber

Information Technology and Training for Emergency Management

As a natural follow-up to the Nordic project NKA/INF and European project ISEM, efforts have continued in two new projects started up at the beginning of 1993: The MUSTER project, related to training the co-ordinated efforts of a distributed group of decision makers in emergency management, and MEMbrain, a large emergency management system meant for coping with territorial emergency situations of various kinds. As an example of a major accident the photograph shows a burning oil tanker in a port area.

MUSTER

"Multi-User System for Training and Evaluation of Environmental Emergency Response" is a project partly funded by EU in the framework of "Environment". It began at the start of 1993 and is expected to last for two years. The consortium consists of 8 EU participants from Denmark, Italy and England, and one participant from Sweden representing the EFTA countries. The overall objective of the project is to develop advanced and efficient means of supporting training to enable well-trained decision makers to work in close cooperation with each other. This objective will be pursued by

1. establishing a methodology which will support multi-user emergency management training and evaluation of emergency management capabilities, and
2. developing the specification of information technological systems supporting the matching of the proposed training and evaluation methodology.

In order to get a good understanding of the domain of training and evaluation, various descriptive models have been developed during 1993 based on interviews with end-users of the MUSTER product:

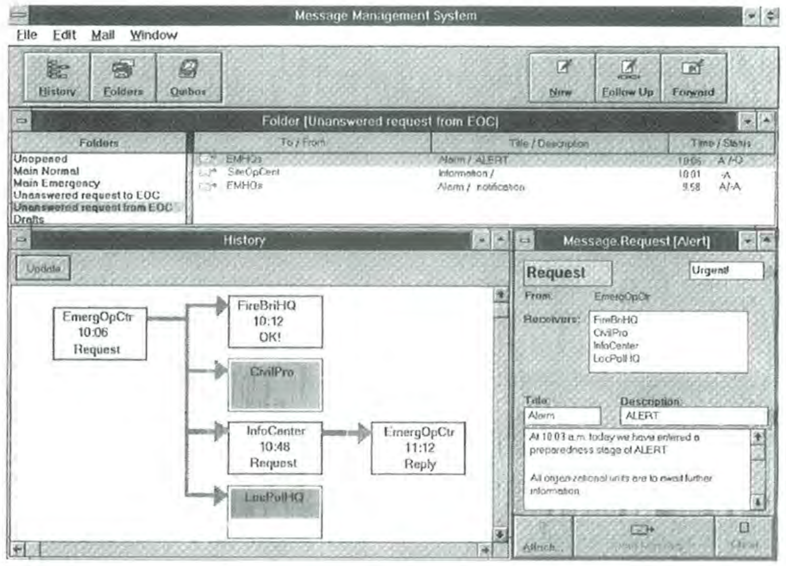
a) a domain model describing the environment for the training session including lay-out of the scenery, overview of available resources, human as well as technical, and scenario descriptions;

b) a training and evaluation model describing the state of the art of training and evaluation within the emergency management domain; and

c) a model describing the state of the art of co-operative working within emergency management; this model includes a description of the organizational set up related to the specific emergency situation and the information flow among the various organizational units.

Based on these models, a set of combined requirements will be extracted in order to describe the needs of the end-users of MUSTER: the training supervisor who designs, executes and evaluates the training sessions, as well as the trainees who are being trained in the cooperative actions.

The end result of MUSTER will be refined requirements for a multi-user training and evaluation system supported by two prototypes illustrating the functionality and user interface of MUSTER.



MEMbrain

"Decision-support Integration-platform for Major Emergency Management" began medio 1993 and is expected to last five years. The project is a joint European project within the framework of EUREKA, and the Danish part is partly funded by the Danish EUREKA authorities (Erhvervs-fremmestyrelsen). The MEMbrain consortium has nine partners from France (project co-ordinator), Denmark, Norway, Finland, Portugal, and Greece, and a vast amount of associated partners and subcontractors. The aim of the project is to define and implement a standard European software and hardware platform for Major Emergency Management (MEM), designed to operate in a variety of national and application domains. This goal will be attained through enhancing the performance of the human actors bearing the responsibility of decision making in the case of Major Emergencies. The Danish team inside MEMbrain – consisting of Risø and the Danish software house IFAD has the responsibility of developing two modules that are essential for all kinds of emergency management systems: the training module related to the MUSTER project discussed above, and a message management system, MMS, the MEMbrain information and communication module.

The design of an MMS system was initially started in a former ESPRIT project, ISEM, in which the system obtained a rather scarce functionality and user interface, the latter just given by the default interface created by the CASE tools used for the developing process. It was subsequently implemented in a modern GUI environment, firstly within an in-house project, and secondly within the MEMbrain project. The MMS system is especially dedicated to emergency management situations; however, in order to be efficient in critical situations, it is of crucial importance that the system be usable and used also in the daily work. The need of decision makers in emergency management is to gain timely and perspicuous information; and some of the main features of the MMS system are

1. to avoid misunderstandings in communication, a problem which according to the analysis of emergency situations often causes less than optimal performance;
2. to indicate if the information forwarded has been received properly, and if this is not the case to be reminded about actions to be taken; and,
3. to offer an overview of the often very complex network of communications necessary for a complex preparedness.

An example of the enhanced user interface of the MMS system is shown in the figure, which also indicates the linking feature that allows the user to see at a glance in a graphic tree display the context in which a given information belongs as well as providing, for instance, a quick view of who has failed to acknowledge a command or to complete an action requested.

The MEMbrain project is going to develop emergency management prototypes for six different pilot projects, and it is the intention in relation to the Danish contribution to deliver integrated communication and training modules for two of these projects, and a framework for user-implemented communication and training modules for the remaining pilot projects.

Publications in 1993: 3, 5 and 6

Verner Andersen

Methods and Technologies Supporting Training for Safety Critical Domains

In recent years an increasing emphasis has been made on human factors issues in safety critical domains. Growing importance is now attached to subject areas such as training, design of man-machine interfaces and team interaction and coordination. Human factors issues have come into focus no doubt in large part because of the growing recognition that "human error" frequently plays an important causal role in major accidents. Also, investments in improving human factors aspects of a safety critical application tend to buy a relatively great safety gain.

Building on a well-known tradition for cognitive studies of the role and nature of human error in man-machine interaction, the Cognitive Systems Group is involved in a range of human factors activities focusing on achieving improved human-machine performance in safety critical domains, in particular *simulation-based training*.

Although on-the-job training is often better than training off-the-job, this is not always the case; the real world is not necessarily the best environment in which to train people. Indeed, training simulators have several advantages: first, they may typically be used without risks to life and health - whereas a real aircraft or a real power plant could become a very risky training environment; second, simulators provide trainees with a possibility of coping with critical situations which they rarely encounter in real life; and third, training simulators are often more cost effective environments and are typically more readily available than real work environments.

The emergency management projects have involved the Group in design efforts centered around specifying a multi-user training environment called the *Scenario Assistant*. This is a generic tool designed to support emergency management trainers in setting up and running training scenarios for tactical training. The *Scenario Assistant* thus provides training supervisors with the means of controlling very complex scenarios which allow trainees to interact with simulations of a range of processes involved in an emergency (e.g., fires, dispersion of toxic plumes, oil spills, evacuation of both personnel and nearby population). The design of the tool has been based on a wide ranging survey of training and evaluation practices in both civilian and military applications. At the same time, Risø has started the development of methods of training coordination abilities for emergency management adapted and modified from the aviation-based crew resource management (CRM) concept for training pilots.

Another training activity has been directed at assessing and improving the training effects of maritime simulators and involves a project commissioned by the Danish Maritime Institute (DMI). The project, which is based on an earlier, successful collaborative effort concerning training and evaluation between the DMI and the Group in 1992, is directed at, first, developing performance evaluation methods; and second, iden-

Assessment of officers' performance in a maritime simulator.

tifying ways to increase the training effects of maritime simulators. The methods developed for evaluating the performance of personnel as they cope with simulated and typically difficult navigation scenarios involve investigations of communication and errors. Thus, comprehensive analyses of communication patterns among crew members as well as human error analyses were conducted by a training supervisor and a cognitive psychologist. Among the results of the project was the clear finding that standby trainees, who assume a mere observer role in relation to the in-session trainees, show a substantial gain in learning. The recommendations derived from the study for increasing the training effects of the simulator environment include therefore having standby trainees observe in-session colleagues whenever convenient; other recommendations advise that trainees make explicit their action rules during debriefings, and that specific training sessions be prepared to improve the communication styles of trainee crews.

A planned Esprit project (MATE - Multi Aircraft Training Environment), which is a new project scheduled to start at the beginning of 1994, seeks to develop a new type of flexible flight simulator. Risø is managing partner of the human factors efforts of the project, and the Group has started a series of studies of the comparative effects of using different types of "virtual" touch-screen technologies to train procedural skills. At the same time, the Group is developing analysis techniques and methods for *multi-modal* recording and analysis of the behaviour of pilots and operators in process control environments: this involves the registering and analysis of different behavioural "modalities", including visual orientation, hand movements, activation of controls and verbal communication.

Finally, the Group has collaborated with Herlev Hospital and Roskilde University in a national project, Sophus, concerned with developing a comprehensive anaesthesia simulator and methods for improving anaesthesia safety. The main purpose of the simulator effort is to provide a flexible environment to train anaesthetists in coping with critical incidents that may arise during general anaesthesia. While no exact record can be made, figures adapted from other countries put the number of anaesthesia-related deaths or severe brain damages to around 1:10,000. Translated to Denmark, this means that about 45 people die or become seriously brain damaged every year because of events related primarily to anaesthesia. So while anaesthesia is indeed very safe and much safer today than a generation ago, there is reason to believe that the level of safety can be improved, not in the least through training efforts. In 1993, the efforts of the Group have been focussed on mathematical modelling and programming and, to a lesser extent, to collaborating with the national partners on a pilot study of performance during anaesthesia, and foreign partners who will now join the project.

At the same time, this type of application serves to illustrate, first, that the cognitive and human factors problems that are involved in improving safety are very much similar across domains involving safety critical process control; and second, that as powerful training simulators are becoming much more affordable, greater opportunities are thereby created for training and studying people as they cope with critical situations.

Publications in 1993: 28, 30, 31 and 32

HENNING BOJE ANDERSEN

Anaesthesia training simulator session.

COMPUTER SUPPORTED COOPERATIVE WORK

The research in Computer Supported Cooperative Work (CSCW) in the Cognitive Systems Group in 1993 has primarily focused on developing the theory of the design of computational mechanisms of interaction for CSCW systems. This research has been supported by the EU Esprit Basic Research Programme (the COMIC project) and the Danish Technological Research Council (the CODEM project of CCI). The research activities have been carried out in close collaboration with other research institutions, in particular University of Milano, University of Manchester, Lancaster University and the Technical University of Denmark.

The research addresses a problem of increasing importance to modern technologically advanced industrial plants, administrative agencies, and service organizations, namely the problem of coordinating and integrating the distributed cooperative activities of multiple actors with respect to highly complex work environments. In such settings, the articulation of the activities of multiple actors itself becomes a highly complex task - due to

- the multifarious and intractable ways in which cooperative activities may interact;
- the irreversibility of cooperative activities that are tightly coupled or performed with respect to a state of the field of work that changes dynamically or is carried out under critical constraints (e.g., safety, time, policy);
- the interplay of myriads of activities that are carried out concurrently, intermittently and indefinitely;
- the operational uncertainties stemming from incomplete, ambiguous and misleading information.

Under such conditions, the everyday social and communication skills are far from sufficient for articulating the cooperative efforts of hundreds or thousands of actors. Rather, the articulation of the distributed activities requires a certain class of symbolic artifacts that stipulate and mediate articulation work and thereby reduce the complexity of articulation work. These artifacts have been termed mechanisms of interaction.

A mechanism of interaction can be defined as a device for reducing the complexity of articulating distributed activities of large cooperative ensembles by *stipulating and mediating* the articulation of the distributed activities. In order to serve this function, such a device must be

1. persistent in the sense that it is accessible independently of any particular situation or individual; that is, it must exist in the form of an artifact;
2. it should be a symbolic artifact in the sense that it is possible to manipulate the mechanism independently of the state of the field of work; that is, the artifact must have the character of a symbolic artifact; and
3. it should provide affordances to and impose constraints on articulation work.

Such artifacts have been in use for centuries – in the form of catalogues, time tables, routing schemas, kanban systems, and so on. Now, given the infinite versatility of computer systems, it is most likely that computer-based mechanisms of interaction can provide a degree of visibility and flexibility to mechanisms of interaction that was unthinkable with previous technologies, typically based on inscriptions on paper or cardboard. This opens up new prospects of moving the boundary of allocation of functionality between human and artifact with respect to articulation work. The challenge is to change the allocation of functionality between human and artifact, not only so that much of the drudgery of articulation work (boring operations that have so far relied on human effort and vigilance) can be delegated to the artifact, but also, and more importantly, so that cooperative ensembles can articulate their distributed activities more safely, timely, reliably etc. and with a higher degree of flexibility and so that they can tackle an even higher degree of complexity in the articulation of their distributed activities!

The aim of providing structured support for the articulation of distributed activities is shared by many researchers in CSCW. However, most of the mechanisms of interaction in existing CSCW systems are experienced as excessively rigid, either because the embedded mechanism of interaction is not visible and cannot be changed, or because the facilities for changing the mechanism do not support respecifying the mechanism by the actors themselves at the semantic level of articulation work. By contrast, in view of the situated character of cooperative work, mechanisms of interaction should be conceived of as local and temporary closures. Accordingly, the primary objective of the CSCW research in the Cognitive Systems Group is to support actors in accessing and manipulating the mechanism of interaction in such a way that they are able to handle contingencies and adapt the stipulations of the mechanisms to changing requirements in their environment.

Now, a number of recent research projects attempt to make CSCW applications flexible at the level of articulation work. While this research is very promising, the approach taken by the CSCW research in the Cognitive Systems Group differs in one important respect, namely the attempt to develop a general notation that is comprehensive enough to specify any mechanism of interaction and yet at the same time supports the specification of mechanisms of interaction in terms of articulation work, by the actors themselves in a cooperative manner.

In order to address this problem, two complementary research activities have been carried out in 1993. On one hand, a comparative study of empirical field studies has been undertaken. The purpose of that investigation is, in general, on the basis of available social science evidence, to develop a conceptual framework of cooperative work and its articulation that can deepen the understanding of articulation work and, in particular, to explore and develop the hypothesis of 'mechanisms of interaction' and to derive design requirements from the way in which symbolic artifacts are used for articulating cooperative activities in real world settings.

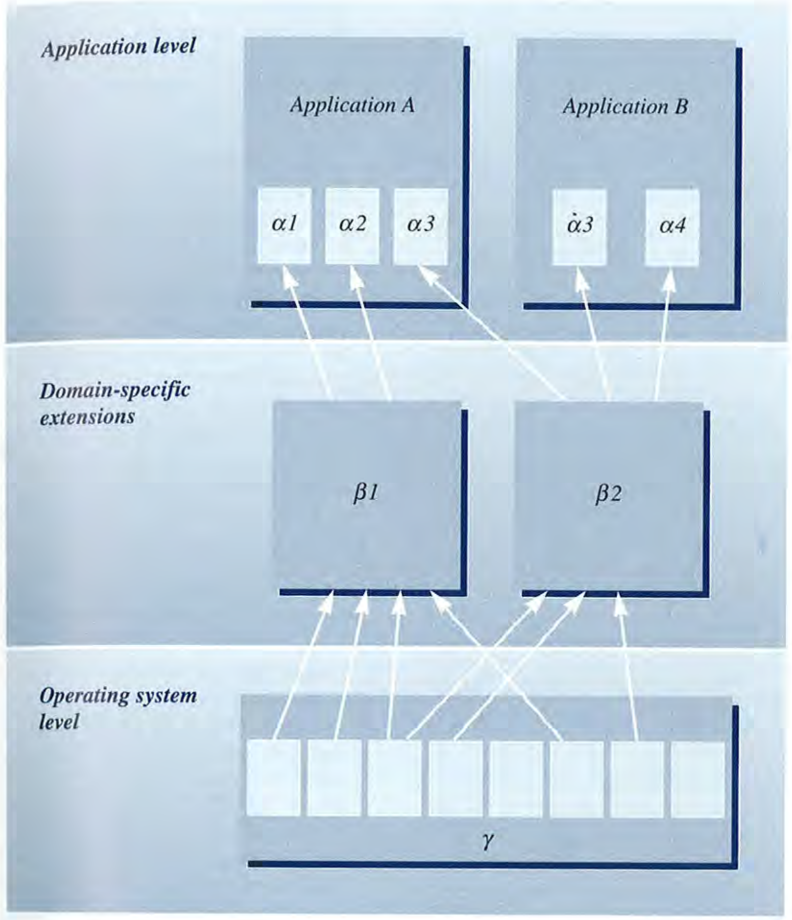
On the other hand, a comparative study of 27 current CSCW systems (applications, shells and models) has been conducted. The purpose of this investigation has been to unravel and define the mechanisms of interaction incorporated in these systems – in order to put the concept of mechanism of interaction to test and to take the initial steps towards developing a general conceptual foundation for the design of mechanisms of interaction for CSCW systems.

As a result of the research in computational mechanisms of interaction in 1993, a conceptual framework has been developed for conceptualizing the requirements of computational mechanisms of interaction in a systematic way as well as for designing and evaluating computational mechanisms of interaction. According to this framework, a computational mechanism of interaction should be conceived of as an abstract device incorporated in a software application so as to support the articulation of the distributed activities of multiple actors with respect to that application and the field of work it represents.

The framework distinguishes two complementary constitutive aspects of a computational mechanism of interaction: notations and facilities.

The research has established that multiple notations are required for controlling and specifying the behaviour of the mechanism. At this point, three notations are hypothesized to be required and sufficient: first, the notation incorporated in the mechanism of interaction and defining its behaviour as a means of stipulating and mediating articulation work (the α notation); second, a β notation is required for enabling actors to specify and respecify the α notation by means of available domain-specific primitives and rules (for instance, reallocating a certain type of task to another type of actor). Third, a γ notation is required for enabling actors to specify and respecify the β notation (for instance, defining a new class of tasks). The β and γ notations are required in order to make mechanisms of interaction sufficiently flexible; in addition, the γ notation is required to support the fluid meshing of different aspects of articulation work by enabling mechanisms to be linked.

The γ notation should be conceived of as a comprehensive notation for specifying domain-specific β notations and, in turn, the application-specific α notations



of the mechanisms of interactions incorporated in different applications. Hence, the γ notation is a general extension of the operating system of workstations and networks. The exact location of the β notation in a CSCW systems architecture is not yet certain. It can usefully, but vaguely, be thought of as domain-specific 'add-on' or 'plug-in' extensions of the operating system.

So far, the three notations required of a mechanism of interaction have only been identified and loosely described. They need to be developed into rigorous design devices. Thus, for the next year, a set of experimental studies of designing α and β notations for specific application domains will be undertaken. Based on previous and current field studies in Danish manufacturing enterprises, the CSCW research activities of the Cognitive Systems Group will be developing mechanisms of interaction for supporting cooperative work in the production and distribution of technical documentation in manufacturing, in production control in flexible manufacturing, and in concurrent design in the manufacturing of electronic equipment.

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Committees

Danish

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Program Committee for CSCW'94, ACM Conference on Computer-Supported Cooperative Work, Chapel Hill, North Carolina, October 24-26 1994.
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Management Committee of COST Action 14 "Co Tech".
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International Advisory Committee for a Workshop on Global Warming Issues in Asia, Asian Institute of Technology, September 1993.
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Steering Committee for the Asian Energy Institute network project on "Asia's and Brazil's contribution to GHG emissions and policy responses for their minimization".
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World Energy Council Study Committee on Renewable Energy Resources.
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Energy Systems Group

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***Jørgen Fenhann**, M.Sc. (Physics with mathematics and chemistry), Senior Scientist.* Niels Bohr Institute 1977. Risø from 1978. Main activities: Development of energy planning models, new and renewable energy technologies, calculation of emissions from energy systems, and energy-environmental planning for Eastern European and developing countries.

***Poul Erik Grohnheit**, M.Econ., Senior Scientist.* Danish Building Research Institute 1969-71, town planning consultant 1971-72 and 1979-80, economic planning and budgetting in local government 1973-79. Risø from 1980. Main activities: Energy system modelling, economics of electricity generating systems, and electricity markets.

***Lotte Schleisner Ibsen**, M.Sc. (Mech.Eng.), Senior Scientist.* Risø from 1984 in Research Section of the Engineering Department working on aquifer thermal energy storage. Joined Energy Systems Group in 1989. Main activity: Assessment of energy technologies especially renewable energy and long-term energy technologies.

***Christina Ingerslev**, M.Sc. (Technological and Socio-Economic Planning) Ph.D. student* at Risø from February 1993. Major subject: Possibilities for reducing the CO_2 emission from dairies and papermills. Subject: Strategies for reducing the CO_2 emission from the manufacturing industry.

***Henrik Klinge Jacobsen**, M.Econ.* Alm. Brand 1989-1991. Greenland Home Rule 1992-1993. Risø from December 1993. Main activity: Macroeconomic modelling.

***Niels A. Kilde**, M.Sc. (Chem.Eng.), Senior Scientist.* The Danish Steelworks Ltd. 1962-81. Research and quality control (1962), planning and administration (1967), casting department manager (1972), development and energy manager (1977). Risø from 1981. Main activities: Energy use in industry and transport, emission inventories.

***Helge V. Larsen**, M.Sc. (Elec.Eng.), Ph.D., Senior Scientist.* Technical University of Denmark 1974. Storno A/S from 1975. Risø from 1976. Department of Reactor Technology 1976-77. Energy Systems Group from 1977. Main activities: CHP production, modelling of energy systems, economic models for the oil and gas sector, development of planning models for wind energy.

***Henrik Jacob Meyer**, M.Econ.* Rockwool Foundation Research Unit 1990-93. Technical University of Denmark 1993. Risø from December 1993. Main activities: Environmental economics, externalities, environmental accounting, valuation of environmental damages and benefits, and utilisation of renewable energy.

***Poul Erik Morthorst**, M.Econ., Senior Scientist.* Economist specialized in energy planning and macro-economics. Risø from 1978. Head of Energy Systems Group 1985-89. Main activities: General energy planning and modelling with emphasis on electricity demand forecasting, economics of renewable energy technologies, especially wind turbines.

Lars Henrik Nielsen, *M.Sc. (Phys.,Math.), Senior Scientist.* Risø from 1981. Main activities: Probabilistic methods and model development, technical-economic modelling, energy system simulation and assessment of energy technologies, especially renewable energy.

Peter Stephensen, *M.Econ. Ph.D.* Student at Institute of Economics, University of Copenhagen 1989-91. Specialized in theoretical economics. Risø from 1991. Main activities: Environmental economics and macro-economic modelling.

Lene Sørensen, *M.Sc. (Eng.), Ph.D.* Started at Risø 1990 as Ph.D. student. Major subject: environmental planning and uncertainty. At International Institute for Applied Systems Analysis in 1991. Activity: evaluation of the RAINS model. Post doc from 1st April 1993 with the Energy Systems Group. Main activities: integrated energy/environmental models, evaluation of models, uncertainty in planning, methodologies for multi criteria assessments.

Risk Analysis Group

Kurt Erling Petersen, *M.Sc., Ph.D.* Risø from 1977. Department of Energy Technology 1977-84. Risk Analysis Group from 1984. Head of Risk Analysis Group from 1990. Deputy head of Systems Analysis Department. Main activities: Risk and reliability analysis and treatment of reliability data.

Palle Christensen, *M.Sc. (Elec.Eng.), Senior Scientist.* Risø from 1962. Electronics Department 1962-86, work on nuclear instrumentation, research instrumentation and reliability projects. Department of Information Technology 1986-88, work on networking knowledge-based computing. Secretary of Risø's patent council 1973-88. Risk Analysis Group from 1988. Main activity: Risk analysis and development of computer codes for reliability and safety analysis.

Carsten D. Grønberg, *M.Sc. (Elec.Eng.).* Risø from 1967. Electronics Department 1967-78. Safety Department 1978-83. Risk Analysis Group from 1984. Main activities: Human factors, emergency management, risk communication, risk management.

Hans E. Kongsø, *M.Sc. (Mech.Eng.), Senior Scientist.* Risø from 1957. Research reactor DR 2 1957-63, Department of Energy Technology 1963-84. Risk Analysis Group from 1984. Main activities: Computer codes for reliability and consequence assessment, and reliability and risk assessment of nuclear and industrial plants.

Kurt Lauridsen, *M.Sc. (Elec.Eng.), Ph.D.(Nuclear engineering),* Senior Scientist. Risø since 1974. Department of Energy Technology 1974-87, working with nuclear safety and industrial risk analysis. Department of Informatics 1987-90. Risk Analysis Group from March 1990. Main activities: Reliability analysis, risk management.

Dan S. Nielsen, *M.Sc. (Elec.Eng.).* Risø from 1962. Electronics Department 1962-84. Risk Analysis Group from 1984. Main activities: Risk analysis of individual plants, physical modelling for consequence assessments.

Søren Ott, *M.Sc. (physics), Ph.D. (Turbulence theory), Senior Scientist.* Risø from 1985. Main activities: Models and computer codes for consequence assessment; dense gas dispersion and flame experiments.

Jette Lundtang Paulsen, *M.Sc. (Mech. Eng.).* DTH 1972. From 1972-80: Research reactor DR3. From 1980-86: Uranium Extraction project. From 1986-90: Department of Informatics. From 1990: Department of Systems Analysis. Main activities: Maintenance planning, software development, interface systems.

Birgitte Rasmussen, *M.Sc. (Chem.Eng.), Ph.D., Senior Scientist.* The Technical University of Denmark from 1981-84. Risø from 1984. Main activities: Risk assessment of industrial activities, hazard identification, risk management, risk communication.

Anette Schnipper, *M.Sc. (Pharm.).* The Royal Danish School of Pharmacy 1989-90. Ph.D. student at Risø from 1990 until July 1993. Subject: Toxic Products in Smoke from Chemical Fires.

Lene Smith-Hansen, *M.Sc. (Chemistry).* Risø from 1986. Main activities: Risk assessment of chemical plants, toxic effects from releases and assessment of chemical warehouse fire consequences.

UNEP Collaborating Centre on Energy and Environment

John Møbjerg Christensen, *M.Sc. (Eng.) Ph.D.* Danish National Agency of Technology 1980-83, R&D initiation and administration, Oilconsult, Consulting Engineers and Planners 1983-84, R&D Energy Planning, NRSE projects. Risø from 1984. Energy Systems Group 1984-88, Energy planning in developing countries, project analysis tools and methods. Programme Officer, Energy Unit, United Nations Environment Programme 1988-90. Head of UNEP Collaborating Centre on Energy and Environment from October 1990. Main activities: energy-environment planning in developing countries, project initiation, UN contacts and coordination.

Pramod Deo, *M.Sc. (Physics) Ph.D. (Infrastructure Economics).* Senior development administrator with 22 years of experience in the Indian State and Central Governments. Founder Director of state and national level energy institutions namely Maharashtra Energy Development Agency (1986-88) and Energy Management Centre (1989-93). Research Engineer at Asian Institute of Technology, Bangkok 1985-86 and Energy Policy Consultant at World Bank 1992-93. From July 1993 with UNEP Collaborating Centre on Energy and Environment as Senior Energy Economist. Main activities: energy-environment planning in developing countries, project development and management, technical support to UNEP.

Kirsten Halsnæs, *M.Econ., Senior Scientist.* Danish Ministry of Housing and Building, 1983. Risø from 1987. Energy Systems Group until end of 1992 with the main activities: Methodologies for energy and environmental modelling. From January 1993 with UNEP Collaborating Centre on Energy and Environment with the main activities: The Economics of Greenhouse Gas abatement, methodologies for abatement cost assessment in developing countries, multi criteria assessment for environmental impacts of energy systems.

Gordon A. Mackenzie, *B.Sc. Ph.D. (Physics), Senior Scientist.* Guest researcher at Risø 1974-78. Lecturer at Edinburgh University 1978-79. Energy Systems Group from 1980. 1984 to 1987 Energy Adviser/Deputy Director at Department of Energy, Zambia. From February 1988 until February 1990 leader of Environmental Modelling Group. From October 1990 with UNEP Collaborating Centre on Energy and Environment as senior energy planner. Main activities: integrated energy/environmental models, energy and environment in developing countries, environmental database.

Umme Salma, *(Econ), Ph.D.* Risø from August 1993. Specilization in economic modelling. Started career as an Economist with the Bangladesh Government. Ph.D. scholar and later Research Associate at the Australian National University during 1985-93. Research area covered: macroeconomic and distributional consequences of changes in government policies in general as well as in partial equilibrium framework. Work at Risø: energy-economy interactions and social cost-benefit analysis.

Joel N. Swisher, *M.S. (Mech. Eng.), Ph.D., (Env. Eng.).* Solar Energy Research Institute (U.S.) 1980-83, consultant to New Zealand Ministry of Energy 1984-85, research engineer with Architectural Energy Corp., Colo., U.S.A. 1986-88. Private engineering consulting practice 1988-1992. Visiting Research Engineer at Lund University, Sweden 1991-93. Main activities: integrated energy-environmental planning in developing countries, electric utility planning models, bottom-up analysis of national costs of reducing carbon emissions, training in energy end-use analysis.

Arturo Villavicencio, *M.Sc. (Math.)* National Energy Institute (Ecuador) 1979-85. Energy Planning Consultant for the Latin American Energy Organisation, CEC and World Bank 1985-88. Energy Adviser at OLADE 1988-90. From May 1991 with UNEP Collaborating Centre on Energy and Environment. Main activities: Energy/environmental models, integrated energy-environment planning in Latin America.

Guest Researchers

Stefán Einorsson, Reykjavik. Guest researcher from 24th August-30th September 1993.

John Flach, Dayton, Ohio. Guest researcher from 30th August-12th September 1993.

Rudolphe Huard, France. Guest researcher from 1st March-May 1993.

Piotr Kowalik, Gdansk, Poland. Guest researcher from 8th March-9th May 1993.

Yew-Kwang Ng, Melbourne, Australia. Guest researcher from 29th November-31st December 1993.

J.P. Painuly, Bombay, India. Guest researcher from 22nd November-21st December 1993.

Jan Scherfig, Ph.D. (Civil Eng.) Professor of Environmental Engineering. University of California Irvine.

Richard E. Sharp, Harwell, UK. Guest researcher from 1st November-18th November 1993.

Eswaren Subrahmanian, Pittsburgh, USA. Guest researcher from 18th October-18th November 1993.

Programmer

Søren Præstegaard, datanom. Regnecentralen 1973-79. Risø from 1979. Datanom with special subject: Optimization completed 1985 at EDP-school, Copenhagen. Working on simulation models, graphics, and general user support.

Secretaries

Maria M. Andreasen
Gytha Egelund
Jette Larsen
Annette Dahl Poulsen
Irma Strandvad

Research Technician

Erling Johannsen

Temporary Staff

Mette Olufsen (M.Sc. student), from Aug 15. Development of library database for UCC and integration of CORINAIR data in the EDB.

Steffen Willumsen Nielsen (information consultant) until 31 March. Software testing, user documentation, and evaluation of user performance under the BOOKHOUSE project.

Henrik Garde, M.Sc. (Com.Sci.), from 15 August. Development of software for message management system for emergency organizations.

Rasmus Nørgård, (Agro.Econ. student), from 15 October. Energy modelling.

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The report describes the work of the Systems Analysis Department at Risø National Laboratory during 1993. The department is made up of the Cognitive Systems Group, the Risk Analysis Group, the Energy Systems Group, and the UNEP Collaborating Centre for Energy and Environment. The report includes lists of publications, lectures and staff members.

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